

Swartz

# The Journal of the INSTITUTE OF METALS

*and*  
**METALLURGICAL ABSTRACTS**

**JOHNS-HOPKINS UNIVERSITY**  
**Applied Physics Laboratory**



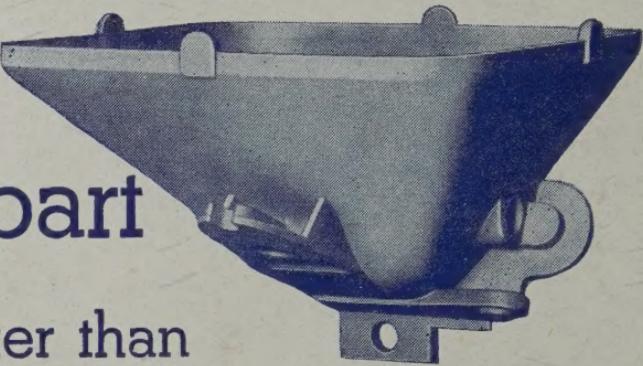
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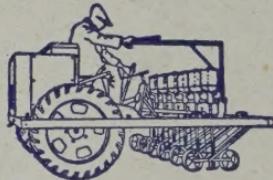
**MARCH 1948**

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this part  
is greater than



this whole



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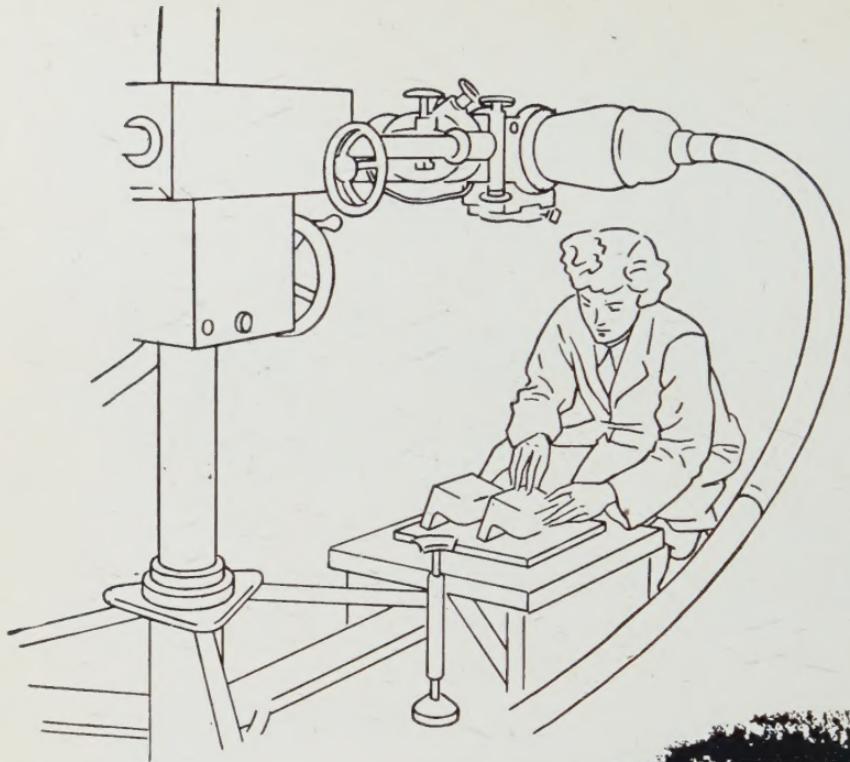
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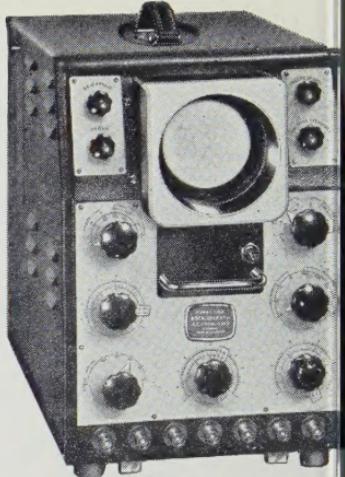
## *Announce*



The Model 1035 is a general purpose Oscillograph, consisting of a Double Beam Tube Unit, Time Base, Y Deflection Amplifiers and internal Power Supplies. The two traces are presented over the full area of a flat screen tube of 90 mm. internal diameter and operating at 2 kv. Signals are normally fed via the Amplifiers, with provision for input voltage calibration. The Time Base is designed for repetitive, triggered, or single stroke operation, and time measurement is provided by a directly calibrated Shift Control.

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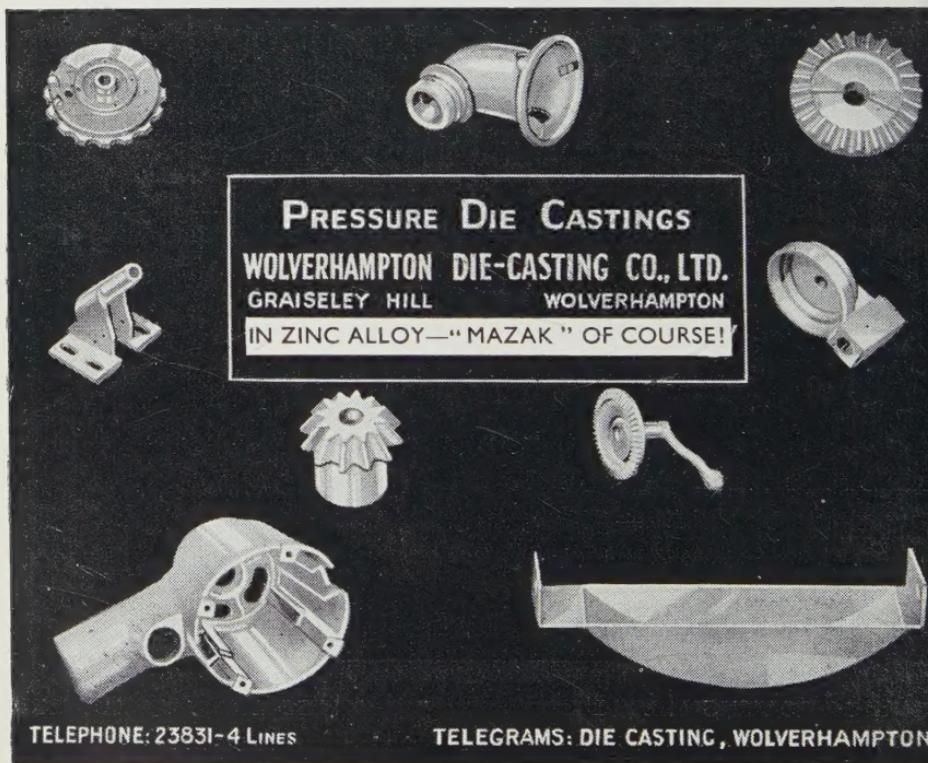


## MODEL 1049

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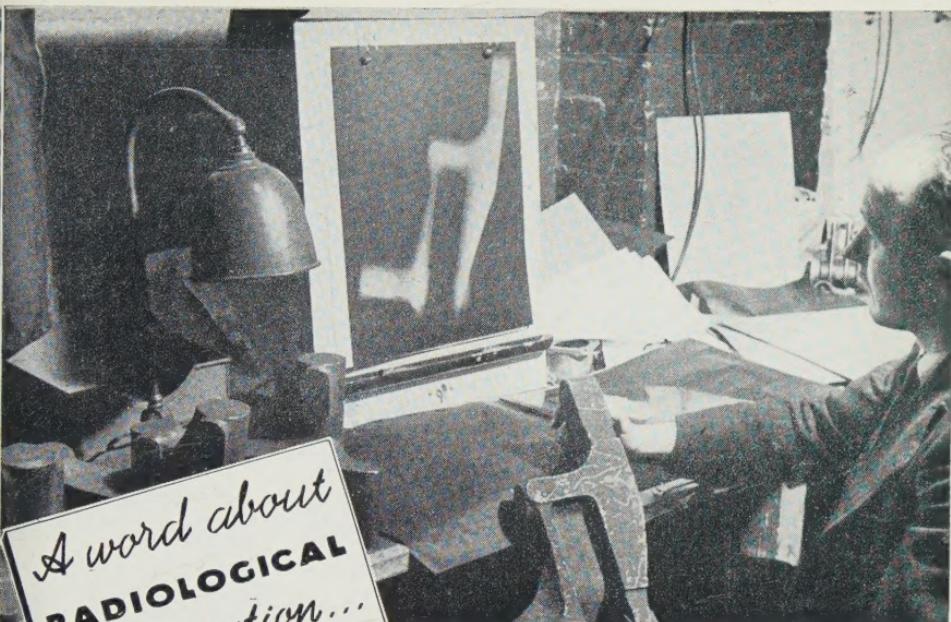
is designed specifically for industrial use where the main interest is in the observation and measurement of low frequency phenomena. Its presentation is generally similar to that of Model 1035 illustrated and a comprehensive specification includes 4 kv. tube operation for transient recording.

CI/31



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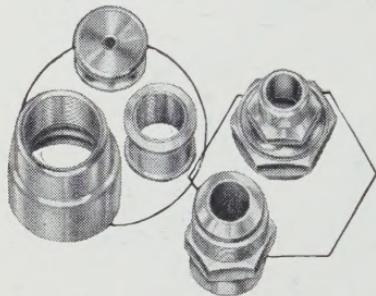
The fluorescent method of crack detection, involving the impregnation of the castings with a fluorescent material and their subsequent examination in ultra violet light, constitutes a useful supplement to X-ray inspection. The application of this method to a light alloy casting is shown above.

The radiological examination of castings, originally developed to meet the requirements of the aircraft industry for highly-stressed light alloy components, has long since been established on a routine basis. Our own very completely equipped radiological department has been in operation for more than ten years . . . Other industries have now come to recognise the value of this penetrating supplementary inspection service and, by specifying "X-ray quality", have been able with advantage to extend their use of non-ferrous castings and reap the full advantage of light alloys in their designs . . . Substantial savings can also be made by the radiological examination of castings calling for a considerable amount of machining: hidden faults are discoverable *before* the casting reaches the machine shop—not on the last operation.

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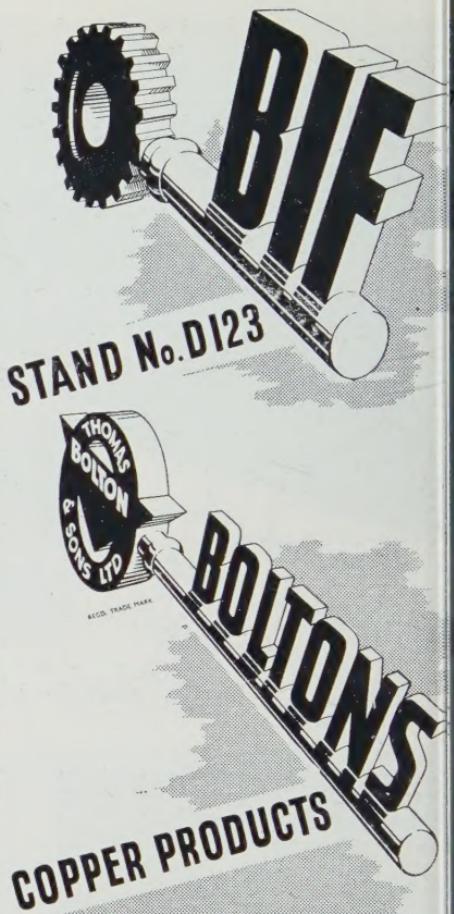
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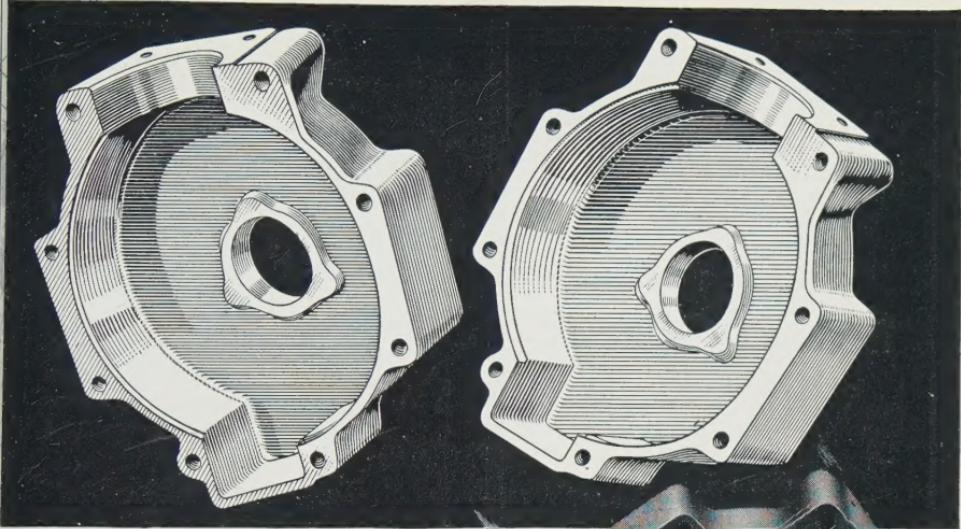
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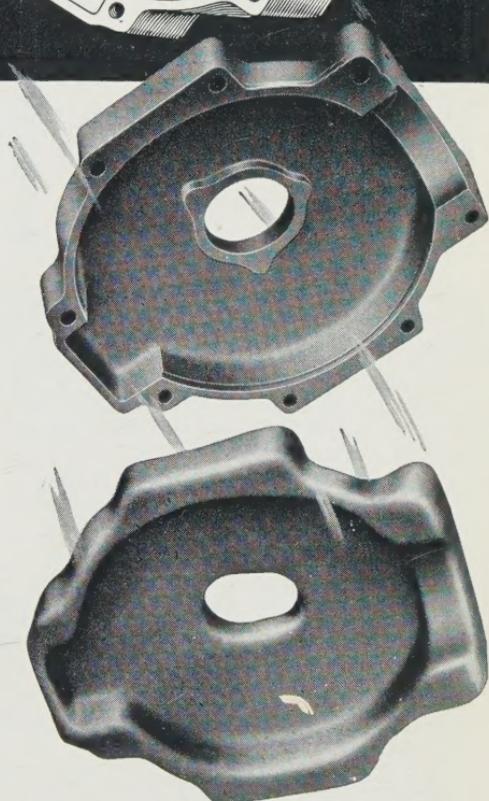
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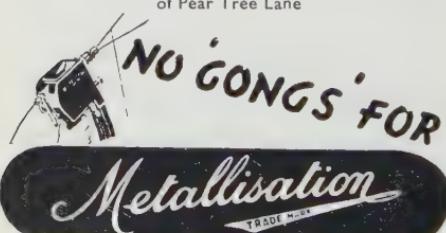
What's the Army got to do with the Mark 16?" asked Tom Sprayitt, with a chuckle. "Army weapons are for 'knocking down'—Mark 16 is for 'Building up.'" To everyone's amazement Mr. Sprayitt produced the pistol itself from behind his back. "Straight off the job" he explained. "Been building up worn gear box shafts all morning."

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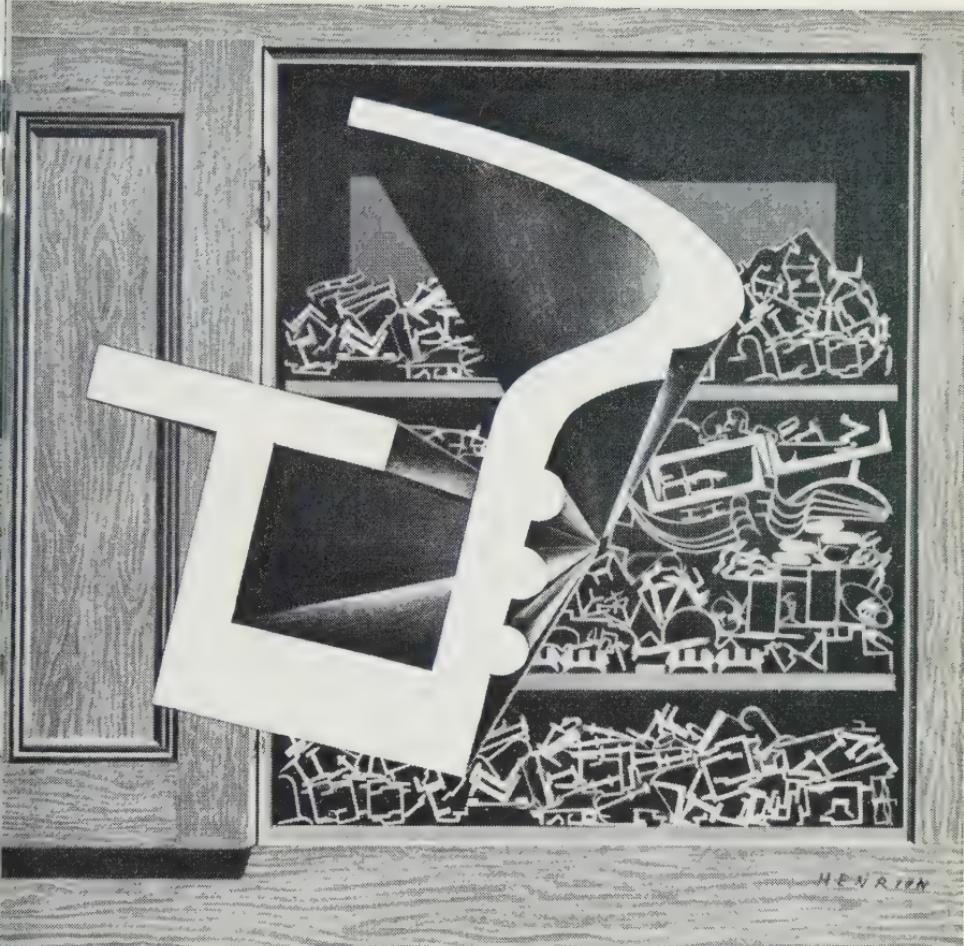
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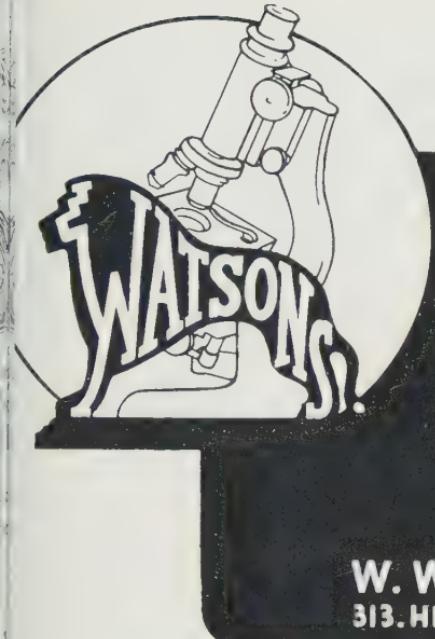


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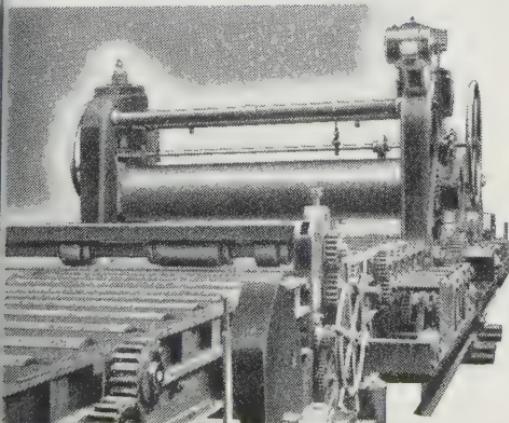
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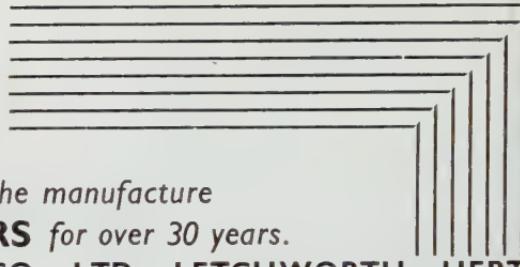
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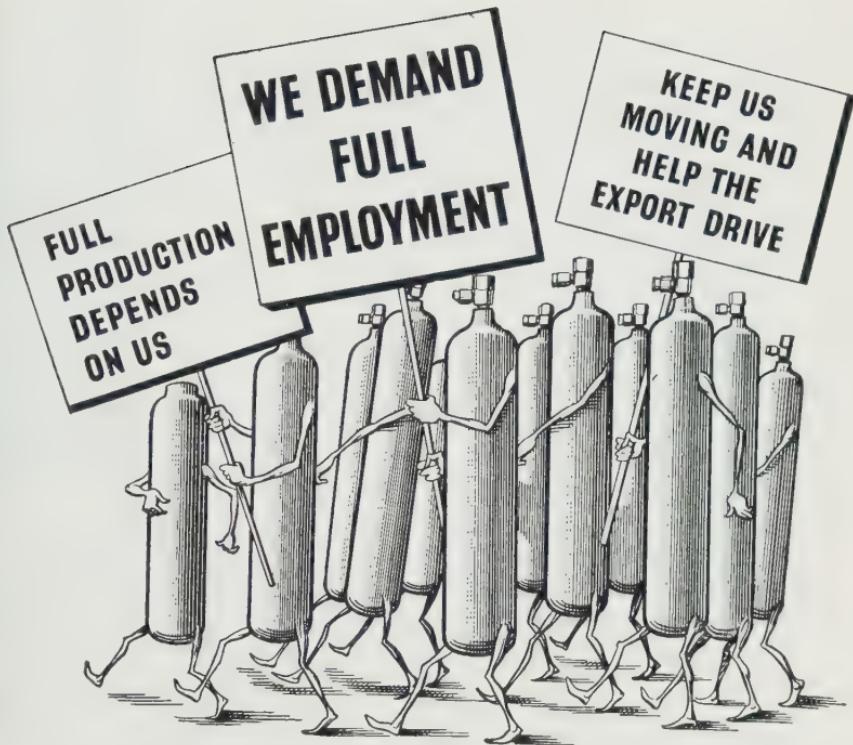


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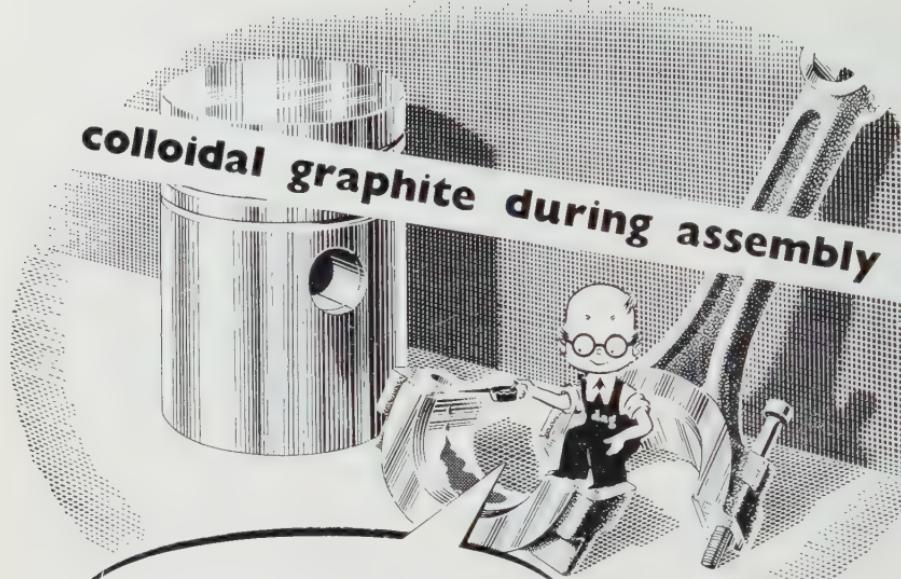
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# THE INSTITUTE OF METALS

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**4 GROSVENOR GARDENS, LONDON, S.W.1**      **SLOANE 6233**

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## INSTITUTE NEWS AND ANNOUNCEMENTS

### ELECTION OF COUNCIL

The following have been elected to fill vacancies on the Council with effect from the 1948 Annual General Meeting of the Institute :

*President :*

Sir Arthur Smout, J.P.

*Vice-Presidents :*

S. F. Dorey, C.B.E., D.Sc., Wh.Ex.  
A. J. Murphy, M.Sc.  
H. S. Tasker, B.A.

*Honorary Treasurer :*

W. A. C. Newman, O.B.E., B.Sc., A.R.S.M., A.R.C.S.

*Ordinary Members of Council :*

D. F. Campbell, M.A., A.R.S.M.  
B. Chalmers, D.Sc., Ph.D.  
T. M. Herbert, M.A.  
D. P. C. Neave, M.A.  
A. R. Powell

### MAY LECTURE, 1948

The 1948 May Lecture will be delivered by Dr. A. O. Rankine, F.R.S., on geophysical prospecting, on Thursday, 13 May, in the Hall of the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, at 6 p.m. Members are requested to note that there will be *no* meeting on the day after the May Lecture.

### AUTUMN MEETING, 1948

The 1948 Autumn Meeting will be held in Cambridge from 14 to 17 September. A very attractive programme is being arranged, and it is hoped that there will be a large attendance.

## NEWS AND ANNOUNCEMENTS

### JOINT MEETING WITH THE BRITISH GLACIOLOGICAL SOCIETY AND BRITISH RHEOLOGISTS' CLUB

In view of the similarities between the flow of ice and of metals, the Council has accepted an invitation to hold a joint meeting, on Thursday, 29 April, with the British Glaciological Society and the British Rheologists' Club. The meeting will be held at 4 Grosvenor Gardens, London, S.W.1.

3.45 p.m.—A film will be shown illustrating the methods of glacier research in the field used by the Jungfraujoch Glaciological Research Party, 1938.

5.0 p.m.—A discussion on the Flow of Ice and of Other Solids will be introduced by Dr. E. Orowan, F.R.S., and Dr. M. F. Perutz.

Members of the Iron and Steel Institute have been invited to attend. Others interested will be welcome.

### MONOGRAPH AND REPORT SERIES NO. 5: SYMPOSIUM ON INTERNAL STRESSES IN METALS AND ALLOYS

The bound volume containing the 36 papers presented to the symposium, held in October 1947, and a full report of the valuable discussions that took place at this two-day meeting, is now in the press.

The price of the volume—which will contain approx. 500 pages and 50 plates—will be 21s., post free, to members, and 42s., post free, to non-members.

As a limited number of the first printing has been ordered, those who desire to purchase copies are requested to send their order at once, with the necessary remittance, to the Institute. Each member is entitled to one copy only of the volume at the special reduced price.

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### PERSONALITIES

#### SIR ARTHUR SMOUT, J.P.

Sir Arthur John Griffiths Smout, who has been elected President of the Institute, was born at Birmingham on 18 November 1888, and was educated at King Edward's School, Birmingham, and Birmingham Technical College. In 1905 he joined the Elliott Group of metal companies as a student apprentice.

From 1920 to 1924 he was Works Manager of Elliott's Metal Company and from 1924 to 1946 Production Director to the Elliott Group, which was merged into Imperial Chemical Industries, Ltd., in 1927. He became Managing Director in 1934 and Chairman from 1934 to 1942 of what is now known as Imperial Chemical Industries, Ltd., Metals Division; he was appointed to the Main Board of Imperial Chemical Industries, Ltd., in 1944, with responsibility for the Company's metal and ammunition interests, and is also a Director of Magnesium Elektron, Ltd., Murex, Ltd., Murex Welding Processes, Ltd., and of Pyrotenax, Ltd. He was Director-General of Ammunition Production at the Ministry of Supply from 1942 to 1945, and was knighted for his services in July 1946.

## NEWS AND ANNOUNCEMENTS

Sir Arthur has devoted much time to public service and to the advancement of science and industry. He is a Justice of the Peace for the City of Birmingham; Life Member of the Court of Governors and Member of Council of the University of Birmingham; Member of the West Midlands Advisory Council for Further Education; Vice-President of the Birmingham Chamber of Commerce; Chairman of the Non-Ferrous Metals Industry Standards Committee of the British Standards Institution; Vice-President of the Institution of Mining and Metallurgy; and a Member of Council of the British Non-Ferrous Metals Research Association, the British Welding Research Association, and the Copper Development Association.

He is a Fellow of the Royal Institute of Chemistry and a Fellow of the Institution of Metallurgists.

Sir Arthur was elected a member of the Institute of Metals in 1917, since when he has given long and devoted service to the Institute. He was a Member of Council from 1924 to 1936, and 1937 to 1940; a Vice-President from 1940 to 1943; a Member of Council from 1945 to 1946; and again a Vice-President from 1946 until his election as President. During the course of these years he has served on many Committees of the Institute and notably in the most important role of Chairman of the Finance and General Purposes Committee from 1946 until assuming the Presidency.

### DR. S. F. DOREY, C.B.E., Wh.Ex.

Dr. Stanley Fabes Dorey, Chief Engineer Surveyor to Lloyd's Register of Shipping, who has been elected a Vice-President of the Institute, was born in 1891, and educated at Owen's School, London, and Armstrong College (now King's College), Durham University, which awarded him the degree of D.Sc.

After an apprenticeship at Chatham Royal Dockyard, Dr. Dorey held a commission in the Royal Navy as Engineer-Lieutenant from 1915 to 1919, and in 1919 was appointed Engineer and Ship Surveyor to Lloyd's Register of Shipping, of which he became Chief Engineer Surveyor in 1933.

Dr. Dorey received the Engineering Gold Medal of the North-East Coast Institution of Engineers and Shipbuilders in 1931 and 1947 and the M. C. James Memorial Medal of the same Institution in 1939; he was awarded the Denny Gold Medal of the Institute of Marine Engineers in 1931 and 1937, and was the Sir Charles Parsons Memorial Lecturer to the Institute of Marine



Engineers in 1942. He has also received the Telford Premium of the Institution of Civil Engineers, the Derby Gold Medal of the Liverpool Engineering Society, and the Still Medal of the Diesel Engine Users' Association, and has been Thomas Lowe Gray Lecturer to the Institution of Mechanical Engineers and

Edward Williams Lecturer to the Institute of British Foundrymen. He received the honour of C.B.E. in 1946.

Besides being a Vice-President of the Institution of Mechanical Engineers, he is Chairman of the Inventions and Research Committee. He is a Past-President of the Institute of Refrigeration, a Vice-President of the Institution of Naval Architects and of the Institution of Marine Engineers and, as well as representing the Institution of Mechanical Engineers and the Institution of Naval Architects on the Engineering Divisional Council of the British Standards Institution, he is Chairman of their Mechanical Engineering Industry Standards Com-

mittee. He is also a member of the D.S.I.R. Mechanical Engineering Research and Fire Research Boards, and of the Home Office Gas Cylinders and Containers Committee (1946), a Vice-President of the British Internal Combustion Engine Research Association, a member of the Research Board of the British Shipbuilding Research Association, a member of the Mechanical Engineering Industry Advisory Committee of the Central Register, Ministry of Labour and National Service, and also a member of several other scientific and technical societies.

Dr. Dorey was elected a member of the Institute in 1933, and has previously served on the Council as a Member of Council (1936-40), and a Vice-President (1940-43).

#### MR. A. J. MURPHY, M.Sc.

Mr. Alfred John Murphy, who has been elected a Vice-President of the Institute, was born in 1901 and educated at Altrincham High School and Manchester University, at which he graduated with First Class Honours in Chemistry in 1920. After leaving the University, he carried out metallurgical research first in the University of Wales (Swansea) from 1920 to 1923 and later under Dr. Walter Rosenhain in the Metallurgy Department of the National Physical Laboratory from 1923 to 1931.

In 1931 Mr. Murphy was appointed Chief Metallurgist to Messrs. J. Stone and Company, Ltd., London, and was made a



## NEWS AND ANNOUNCEMENTS

Director of the firm in 1946. He is also a Director of Stone-Fry Magnesium, Ltd., of London. He is the author of numerous papers on non-ferrous and ferrous metallurgy and metallographic methods, several of which have been published in the Institute's *Journal*.

Elected a Member of Council of the Institute in 1939, Mr. Murphy was elevated to the Vice-Presidency in 1943 and remained on the Council until 1946, when he retired in accordance with the Articles of Association; he was again elected a Member of Council in 1947. From 1938 to 1946 he was Chairman of the Publication Committee, and, in that capacity, performed outstanding service to the Institute. He was one of the Institute's two original representatives on the Joint Committee for National Certificates in Metallurgy.

Mr. Murphy is a Member of Council and Chairman of the Research Board of the British Non-Ferrous Metals Research Association, a member of committees of the British Standards Institution, and a Fellow and Member of Council of the Institution of Metallurgists. He is also a member of several other societies, including the American Society for Testing Materials, the Société Française de Métallurgie, and the Institute of British Foundrymen.



### MR. H. S. TASKER, B.A.

Mr. Hubert Sanderson Tasker, who has been elected a Vice-President of the Institute, was born in 1885 and educated at King Edward's School, Birmingham, and Emmanuel College, Cambridge (Scholar). He joined the staff of Cookson and Company, Ltd., Newcastle-upon-Tyne, in 1910, and became a Director of the Company in 1920.

In 1927 he was appointed Managing Director of Associated Lead Manufacturers, Ltd., and subsequently Managing Director of Goodlass Wall and Lead Industries, Ltd., on the formation of that Company in 1931. He became Vice-Chairman in 1940 and



Chairman in 1947. He is also Chairman of the British Titan Products Company, Ltd.

Mr. Tasker is a Vice-President of the British Non-Ferrous Metals Research Association. He was elected a member of the Institute in 1933, and served as Member of Council from 1938 to 1942 and as a Vice-President from 1942 to 1945. He was Chairman of the Finance and General Purposes Committee from 1940 to 1944, and from 1945 to 1947 was Honorary Treasurer, in which capacity he performed outstanding service to the Institute.

#### MR. W. A. C. NEWMAN, O.B.E.

Mr. William Alfred Cyril Newman, who has been elected Honorary Treasurer of the Institute, was born in 1890. From 1908 to 1910 he studied at the Royal College of Science, obtaining

an Associateship in Chemistry, and from 1910 to 1912 at the Royal School of Mines, obtaining an Associateship in Metallurgy; he was also Bessemer Medallist in Metallurgy. In 1911 he was awarded the B.Sc. (Hons.) Chemistry degree of London University, and in the following year received the Diploma of the Imperial College of Science and Technology and became an Associate of the Institute of Chemistry; this was followed by Fellowship of that Institute in 1915.

After a short period with Messrs. Riley and Harbord, Consulting Metallurgists, Mr. Newman joined the staff of the Royal Mint, London, in 1912, as Assistant Assayer; he became Senior Technical Assistant in 1923, and Assayer in 1937.

He was seconded during the 1914-18 war to the Ministry of Munitions for service as Assistant Manager at H.M. Factory, Queensferry, where he was engaged in the manufacture of acids and explosives, and in work in wood distillation factories (1919-23). In the recent war he was seconded in 1940 to the Ministry of Supply as Assistant Controller, Non-Ferrous Metals Control. He was appointed Chemist and Assayer at the Royal Mint in 1945.

Mr. Newman was elected a Fellow of the Institution of Metallurgists in 1946; served from 1936 to 1938 on the Council of the Electrodepositors' Technical Society, and has served from 1937 to the present date on the Council of the Institution of Mining and Metallurgy, being a Vice-President from 1943 to 1946. From 1938 to 1940 he acted as Chairman of the London Local Section of the Institute of Metals. From 1919 to 1940 he was Lecturer in Metallurgy at the Sir John Cass Technical Institute and in 1939 was recognized as a Teacher of Metallurgy in the University of



## NEWS AND ANNOUNCEMENTS

London. Mr. Newman was appointed an Officer of the Order of the British Empire in 1948.

Mr. Newman was elected a member of the Institute in 1922; he has served on the Council from 1938 to 1940 as Chairman of the London Local Section and again from 1944 until his appointment as Honorary Treasurer in 1947.

### PERSONAL NOTES

DR. ROBERT J. ANDERSON, Met.E., has resumed his consulting engineering practice, specializing in the metallurgy of aluminium and magnesium. Pending his removal to a permanent location, his address is 125 N. Portage Path, Akron 3, O., U.S.A.

DR. S. AUERBACH is now Managing Director of the International Electro Metal Corporation, Ltd., 2 Caxton Street, London, S.W.1.

MR. ALAN R. BAILEY, B.Sc., A.I.M., has been appointed Senior Lecturer in Metallurgy at the Constantine Technical College, Middlesbrough, and commences his duties in April.

MR. QUINCEY BENT, A.B., has retired as Vice-President in charge of the steel-division operations of the Bethlehem Steel Corporation, but will continue to serve the Company in an advisory capacity.

MR. W. B. BROOKS, formerly Metallurgist to the Alloys Development Company, is now in practice as a Consulting Metallurgist at 615 Park Building, Pittsburgh, Pa., U.S.A.

MAJOR P. R. CLARK, R.A.O.C., has left Kure; his present address is HQM, 34th Australian Infantry Brigade, B.C.O.F., Hiro, Japan.

MR. R. J. L. EBORALL has been appointed head of the General Metallurgy Section of the British Non-Ferrous Metals Research Association.

DR. U. R. EVANS has been awarded the degree of D.Sc., *honoris causa*, of Dublin University.

DR. E. W. FELL, M.Sc., F.R.I.C., F.I.M., has been appointed Senior Assistant in Metallurgy at the Bradford Technical College. Courses at the College which are being arranged, or are under consideration by Dr. Fell, are designed to meet the needs of students who desire to take metallurgy (which includes courses leading to the external examinations of London University and the City and Guilds of London Institute) for National Certificates in Metallurgy and for the examinations of the Institution of Metallurgists.

MR. P. T. GILBERT, B.Sc., A.R.I.C., has been appointed head of the Corrosion Section of the British Non-Ferrous Metals Research Association.

MR. N. W. GRIFFIN, B.Sc., A.R.S.M., has arrived in England. His address is c/o Williams Harvey and Co., Ltd., Mellanear Works, Bootle, Liverpool 20, until May, when he expects to leave for the Eastern Smelting Co., Ltd., Penang, Malayan Union.

## NEWS AND ANNOUNCEMENTS

MR. A. HAZELL, B.Sc., has left the die-casting department of the B.T.H. Co., Birmingham, and has joined the staff of Wm. Mills, Ltd., Wednesbury. He will be responsible for the development of a pressure casting section.

DR. W. D. JONES, M.Eng., F.I.M., consultant metallurgist, has left for an extensive trip to South Africa to study the development of powder metallurgy there.

SIR K. S. KRISHNAN, D.Sc., F.R.S., has left the University, Allahabad, on appointment as Director of the National Physical Laboratory, University Buildings, Delhi, India.

MR. J. E. MILLER is now London Manager of the Chesterfield Tube Co., Ltd., at The Adelphi, Strand, London, W.C.2.

MR. B. H. MORGAN, B.Sc., A.I.M., has left High Duty Alloys, Ltd., to become Assistant Metallurgist to Birlec, Ltd., Birmingham.

M. JEAN PAÏDASSI has left France ; his address is Casilla 169, Conception, Chile.

PROFESSOR C. E. PEARSON, M.Met., is resigning in April from the William Cochrane Chair in Metallurgy at King's College, University of Durham, to take up a post with Durham Chemicals, Ltd., Birtley, Co. Durham. Professor Pearson is the first holder of the William Cochrane Chair, which was created in 1945.

DR. G. V. RAYNOR, M.A., who has received a Beilby Memorial Award of £105 for 1947 in recognition of his researches on the constitution of alloy systems, was born in Nottingham and educated at Nottingham High School, whence he proceeded in 1932 to Keble College, Oxford. He was placed in the 1st Class of the Honours School of Natural Science (Chemistry) in 1936 and, after a year of post-graduate research on copper alloys in the Inorganic Chemistry Laboratory of the University of Oxford under Dr. W. Hume-Rothery, became research assistant to the latter for work on factors affecting the formation of magnesium alloys. After election to a D.S.I.R. Senior Research Award, he continued investigations on magnesium alloys and obtained the degree of D.Phil. in 1939. During the war period Dr. Raynor was concerned, in association with Dr. Hume-Rothery and others, with work on the constitution of certain steels and aluminium alloys on behalf of the Service Ministries. Early in 1945 he entered the Metallurgy Department of the University of Birmingham as Research Fellow and became Reader in Theoretical Metallurgy two years later. His work in Birmingham has been directed towards a better understanding of the theory of alloy formation, with particular reference to the behaviour of the transitional metals, and the factors governing equilibrium relations in ternary alloys. Dr. Raynor is a Fellow of the Royal Institute of Chemistry and of the Institute of Physics, and serves on several metallurgical research committees. He is the author or joint author of numerous papers published in the *Proceedings of the Royal Society*, the *Journal of the Institute of Metals*, the *Philosophical Magazine*, and other scientific periodicals, and also of Institute of Metals Monograph No. 4 on "An Introduction to the Electron Theory of Metals" and the series of Annotated Equilibrium Diagrams published by the Institute.

## NEWS AND ANNOUNCEMENTS

MR. V. SUBRAMANIAM, B.Sc., B.Met., is now at the Department of Metallurgical Engineering, 109 State Hall, University of Pittsburgh, Pittsburgh 13, Pa., U.S.A.

MR. H. S. TASKER, B.A., Chairman of Goodlass Wall and Lead Industries, Ltd., who is on a visit to the U.S.A., expects to return at the end of March.

FLIGHT-LIEUTENANT H. H. WATKINSON has left Kasfaret; his present address is Officer's Mess, R.A.F.H.Q., MED/ME., R.A.F., Abu Sueir, M.E.F.

MR. H. WILLIAMS, F.R.I.C., F.I.M., Osram-G.E.C. Lamp Works, Wembley, is acting as organizer of the Wembley Lunch-Hour Discussion Group of the Institution of Works Managers.

### DEATH

The Editor regrets to announce the death in January 1948, of Mr. James Charles Minton, of Charles Harbage, Ltd., Birmingham.

*Note* : Will members (in addition to informing the Institute's administrative department of changes of address, occupation, &c.) kindly notify the Editor, separately, of all changes of occupation, appointments, awards of honours and degrees, &c., as these are matters which interest their fellow members. Such notes should reach the Editor not later than the 21st day of each month, for publication in the next month's issue.

### ELECTION OF ORDINARY MEMBERS AND STUDENT MEMBERS

The undermentioned 18 Ordinary Members and 26 Student Members were elected on 11 February 1948 :

#### As Ordinary Members

BAER, Frank Louis, Chairman and Managing Director, Metal Traders, Ltd., 7 Gracechurch Street, London, E.C.3.

BAILLIE, James, Chief Metallurgist, Acton Bolt, Ltd., Chase Road, London, N.W.10.

BARLOW, Maurice William, Representative, British Electro Metallurgical Company, Ltd., Wincobank, Sheffield.

BROWN, Frederic Greenaway, Manager, Metals Division, Brown Brothers, Ltd., Great Eastern Street, London, E.C.2.

CARSON, Professor Orrin A., B.Sc., A.M., Ph.D., Associate Professor of Metallurgy, Queen's University, Kingston, Ont., Canada.

CHELIOTI, George, Director, General Electric Company, Ltd., and General Manager, Osram-G.E.C. Group, Hammersmith, London, W.6.

COHEN, Joseph Norman, Director, A. Cohen and Company, Ltd., 148/9 Great Dover Street, London, S.E.1.

DENARO, Louis Frederick, Development Engineer, The Mond Nickel Company, Ltd., Grosvenor House, Park Lane, London, W.1.

## NEWS AND ANNOUNCEMENTS

DIXON, Harold Francis, Mechanical Engineer, Imperial Chemical Industries, Ltd., Metals Division, Kynoch Works, Witton, Birmingham 6.

HUTCHINGS, F. G. B., City Librarian, Central Library, Leeds.

IMRIE, William Miller, Assoc.Met., Metallurgist, Rotol, Ltd., Gloucester.

MARSHALL, Peter Robert, B.Sc., Ph.D., Manager, Physics Department, Ferodo, Ltd., Chapel-en-le-Frith, Stockport.

MILLER, Thomas William, M.A., B.Sc., Consulting Engineer, 2 Field Lane, Letchworth, Hertfordshire.

REDDI, Dvan Venkata, B.Sc., B.E.M., Metallurgical Investigator, Inspectorate of Metal and Steel, Ishapore (West Bengal), India.

SCOTT, Lindsay, Managing Director, Fricker's Metal and Chemical Company, Ltd., Portland Road, Luton, Bedfordshire.

SPEAKMAN, John Edward Davan, B.Sc., Engineer and Director, 46 Rutland Park, Sheffield 10.

SPENCER, Kenneth Humphrey, Chief Technical Officer, Metters, Ltd., Sydney, Australia.

SULLY, Arthur Henry, M.Sc., Ph.D., Principal Physicist, Fulmer Research Institute, Stoke Poges, Buckinghamshire.

### As Student Members

DAVIES, Graham Hill, Student, University College, Swansea.

DEVINE, Frank, Student of Metallurgy, Leeds University.

DICK, Raymond Henry, B.Met.Eng., Bureau of Ships, Navy Department, Washington, D.C., U.S.A.

EVANS, Edward Thomas Kenneth, Student, University College, Swansea.

EVANS, Windsor, Student, University College, Swansea.

GLENNY, Robert Joseph Irvine, B.Sc., Metallurgist, National Gas Turbine Establishment, Whetstone, nr. Leicester.

GRIFFITHS, Vernon, Student, University College, Swansea.

HEPTONSTALL, Peter, Student of Metallurgy, Leeds University.

IRELAND, Robert Leslie, Student, University College, Swansea.

JEFFORD, Godfrey, Student, University College, Swansea.

JENKINS, John, Student, University College, Swansea.

JONES, William John, Student, University College, Swansea.

MCKNIGHT, Ian Bertram, Student of Metallurgy, Leeds University.

MARGOLIN, Harold, M.E., Student of Metallurgy, Yale University, New Haven, Conn., U.S.A.

MORGAN, William Robert, Student, University College, Swansea.

PREECE, Robert Lincoln, Student, Birmingham University.

PURCELL, Philip Ralph, B.A., Research Chemist, Stewarts and Lloyds, Ltd., Corby, Northamptonshire.

PURNELL, Alan John, Student of Metallurgy, University College, Cardiff.

RICHARDS, John Rees Morgan, Student, University College, Swansea.

SAUNDERS, William Bernard John, Student of Metallurgy, Central Technical College, Birmingham.

SLATTERY, Gerard, B.Sc., Student, University College, Swansea.

THOMAS, Ithel Orfry Vivian, Student, University College, Swansea.

THOMAS, William Kenneth Leslie, Student, University College, Swansea.

## NEWS AND ANNOUNCEMENTS

VERNEY, Leslie Reginald, Student, University College, Swansea.  
WOODHOUSE, John T., Student of Metallurgy, The University, Leeds.  
WORN, David Kenneth, B.Sc., Research Physicist, General Electric Company, Ltd., Wembley, Middlesex.

## OTHER NEWS

### BEILBY MEMORIAL AWARDS

The Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry, and the Society of Chemical Industry, normally meet once a year to consider the making of awards from the interest derived from the invested capital of the Fund. These awards are made to British investigators in science as a mark of appreciation of distinguished work, particularly in such fields as fuel economy, chemical engineering, and metallurgy in which Sir George Beilby's special interests lay. In general, the awards are not applicable to the more senior investigators, but are granted as an encouragement to younger men who have done independent work of exceptional merit over a period of years.

Owing to the war, no awards were made in respect of the years 1941-46 inclusive, but at a recent meeting of the Administrators it was decided to revert to normal practice and to make awards for 1947 to the following investigators: Geoffrey Vincent Raynor, M.A., D.Phil., F.R.I.C., F.Inst.P., for his researches on the constitution of alloy systems, and George Reginald Rigby, B.Sc., Ph.D., A.R.C.S., D.I.C., A.R.I.C., for his researches on refractory materials.

### FIRST INTERNATIONAL POWDER METALLURGY CONFERENCE, GRAZ, 12-16 JULY 1948

By arrangement with the authorities and representatives of International chemical science and industry, the Steirmark branch of the Association of Austrian Chemists is arranging an International Powder Metallurgy Conference to be held from 12 to 16 July 1948, in Graz. Lectures by leading experts and discussions will furnish a comprehensive picture of the position and problems of the scientifically, industrially, and economically important field of powder metallurgy and allied subjects. The Organizing Committee consists of Prof. Dr. G. Jantsch (Technische Hochschule, Graz); Dr. R. Kieffer (Metallwerk Plansee, Reutte, Tirol); Prof. Dr. O. Kratky (Universität, Graz); and Prof. Dr. G. F. Hüttig (Technische Hochschule, Graz). Further information may be obtained from Dr. C. Sykes, F.R.S., The Brown-Firth Research Laboratories, Princess Street, Sheffield, or Mr. M. Littman, The Compound Electro Metals, Ltd., 42 Pall Mall, London, S.W.1.

### ASSOCIAZIONE ITALIANA DI METALLURGIA

The second national meeting of the Associazione has been postponed until 23-25 April 1948, and will take place in Milan

## NEWS AND ANNOUNCEMENTS

at the same time as the XXVI Exhibition. The first day of the meeting will be devoted to discussions on the subjects of corrosion and of the ageing of metals. Enquiries regarding the meeting, and for accommodation, should be addressed to the Associazione at Via S. Paolo 10, Milano, Italy.

### SYMPOSIUM ON THE PEELING OF WHITEHEART MALLEABLE CAST IRON

A meeting to discuss the peeling of whiteheart malleable cast iron and the penetration of sulphide in the carburization of steel will be held by the Iron and Steel Institute at 4 Grosvenor Gardens, London, S.W.1, on Thursday, 8 April 1948, at 2.0 p.m.

A buffet luncheon (price 6s. per ticket) will be served at 1.0 p.m., before the meeting.

The papers for discussion have been published in the Nov. 1947 and Jan. 1948 issues of the *Journal of The Iron and Steel Institute*.

Persons who are not members of the Iron and Steel Institute can obtain advance copies of the papers and a ticket for the buffet luncheon by sending their application, accompanied by a remittance for 10s., to the Secretary of the Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

### X-RAY CRYSTALLOGRAPHY SUMMER SCHOOL

A summer school in X-ray Crystallography will be held in September in the Physics Department of the Manchester College of Technology, under the direction of Dr. H. Lipson. The course is designed to meet the needs of those who wish to make use of X-ray diffraction in both industrial and academic research, but who have not had opportunity to acquire the basic training.

Further details may be obtained from the Director of Extra-Mural Studies, The University, Manchester 13.

### SUMMER SCHOOL IN THEORETICAL PHYSICS, WITH PARTICULAR APPLICATION TO THE THEORIES OF CREEP IN METALS

A summer school in theoretical physics, with particular application to creep in metals, will be held in the H. H. Wills Physical Laboratory of the University of Bristol, beginning at 10 a.m. on 2 June and ending on 5 June 1948.

The course is similar in conception to that already held on the electrical properties of solids in June 1946, and on mechanical properties of metals in July 1947. It is intended mainly for members of the staffs of Government and industrial laboratories who wish to familiarize themselves with the theoretical side of subjects with which they have been concerned on the experimental side. Lectures will be given by Professor N. F. Mott and other members of the staff of the H. H. Wills Physical Laboratory.

In addition to the regular lectures, there will be opportunities for research workers attending the course to discuss their own work and its theoretical implications. Much of the course will deal with developments that have taken place since the summer school last year, though it will *not*, of course, be assumed that students attending this course were present then. On the other hand, some familiarity with the concept of dislocations as explaining slip will be advisable.

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Subjects to be treated will include: Anelastic effects due to slip at grain boundaries; grain growth, recrystallization and the theory of grain boundary slip; geometry of dislocation and the theory of slip bands; theory of transient creep; slip in solid solutions; diffusion of carbon in iron and elastic after effect; effects of carbon on the mechanical properties of iron; mechanisms of internal damping; crystal growth and the origin of dislocations.

The number attending the course will be limited to about 50; the fee for the course is 5 guineas. Further particulars and forms of application, to be returned by 15 April, can be obtained either from the Director of the Department of Adult Education, The University of Bristol, or from the Secretary of the Institute of Physics, 47 Belgrave Square, London, S.W.1.

The University of Bristol in co-operation with the Institute of Physics announce also a second summer school in physics of solids (experimental and theoretical) to take place in Bristol from 8 to 15 September next, the subject being "The Oxides and Ionic Crystals". Further details will be announced in due course.

### BRITISH INDUSTRIES FAIR

The British Industries Fair will be held from 3 to 14 May 1948. The metallurgical and engineering exhibits will be displayed, as usual, at Castle Bromwich, Birmingham.

Manufacturers are reminded that their early co-operation is invited in providing advance information of their exhibits, so that the world press may refer to the Fair in more than general terms and thus assist by informing buyers of details of specific trade sections.

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## DIARY FOR APRIL

### LOCAL SECTIONS MEETINGS

**Birmingham Local Section.**—Annual General Meeting, followed by Chairman's Address by Mr. E. A. Bolton, retiring Chairman. (James Watt Memorial Institute, Great Charles St., Birmingham, Thursday, 22 April, at 6.30 p.m.)

**London Local Section.**—Annual General Meeting. Open Discussion on "The Oxidation of Metals", to be introduced by short papers by Professor N. F. Mott and Dr. J. H. Mitchell. (4 Grosvenor Gardens, London, S.W.1, Thursday, 8 April; A.G.M., 6 p.m.; papers, 7 p.m.)

**Scottish Local Section.**—Mr. Edwin Davis: "The Mechanical Working of Non-Ferrous Metals". (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, Monday, 12 April, at 6.30 p.m.)

**South Wales Local Section.**—The meeting provisionally arranged for Tuesday, 20 April, is *cancelled*.

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## NEWS AND ANNOUNCEMENTS

### OTHER-MEETINGS

#### THURSDAY, 1 APRIL

**Leeds Metallurgical Society.**—Ivor Jenkins: “Controlled Atmospheres”. (Main Lecture Theatre, Chemistry Dept., The University, Leeds, at 7 p.m.)

#### MONDAY, 5 APRIL

**Cleveland Institution of Engineers.**—Barry Thomas and Frank Kennedy: Discussion Meeting on “Oil-Firing of Open-Hearth Furnaces”. (Cleveland Scientific and Technical Institution, Corporation Rd., Middlesbrough, at 6.30 p.m.)

**Institute of the Motor Industry, Leeds Centre.**—R. J. Brown: “Failures of Materials in Service”. (Leeds and County Conservative Club, South Parade, Leeds 1.)

**Institution of Electrical Engineers, North-Eastern Centre.**—M. E. Haine: “The Design and Construction of a New Electron Microscope”. (Neville Hall, Westgate Rd., Newcastle-on-Tyne, at 6.15 p.m.)

#### TUESDAY, 6 APRIL

**Institution of Civil Engineers.**—R. A. Foulkes: “The Use of Light Alloys in Structures”. (The Institution, Great George St., London, S.W.1, at 5.30 p.m.)

**Institution of Engineers and Shipbuilders in Scotland.**—S. J. Harley: “Standardization”. (The Institution, 39 Elmbank Crescent, Glasgow, C.2, at 6.30 p.m.)

#### WEDNESDAY, 7 APRIL

**Institution of Works Managers.**—D. G. Petrie: “Production Planning: Output versus Paper”. (Waldorf Hotel, Aldwych, London, W.C.2, at 6.30 p.m.)

**Royal Society of Arts.**—“Craftsmanship”. VI.—“Metal-work”, by J. Seymour Lindsay. (The Society, John Adam St., Adelphi, London, W.C.2, at 2.30 p.m.)

#### THURSDAY, 8 APRIL

**Institute of Fuel, East Midland Section.**—S. N. Duguid: “The Fight for Fuel Efficiency”. (Gas Demonstration Theatre, Nottingham, at 5 p.m.)

**Institute of Welding, South London Branch.**—Annual General Meeting, followed by a short programme of films. (Institute of Marine Engineers, 85 The Minories, London, E.C.3, at 6.30 p.m.)

**Iron and Steel Institute.**—Symposium on the Peeling of White-heart Malleable Iron. (4 Grosvenor Gardens, London, S.W.1, at 2.0 p.m.)

#### FRIDAY, 9 APRIL

**West of Scotland Iron and Steel Institute.**—J. M. Mowat and J. Sloan: “A Simple Laboratory Test to Determine Data Necessary for Production Heat-Treatment Processes”. (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, at 6.45 p.m.)

## NEWS AND ANNOUNCEMENTS

### MONDAY, 12 APRIL

**Royal Institute of Chemistry, Hull and District Section.**—Dr. U. R. Evans: “The Electrochemical Mechanism of Corrosion”. (Royal Station Hotel, Hull, at 7 p.m.)

### TUESDAY, 13 APRIL

**Institute of Marine Engineers.**—R. F. Bishop: “The Radiography of Welds”. (The Institute, 85 The Minories, London, E.C.3, at 5.30 p.m.)

**Institution of Works Managers, Liverpool Branch.**—F. E. Chappell: “Production Efficiency”. (Exchange Hotel, Liverpool, at 6.45 p.m.)

### WEDNESDAY, 14 APRIL

**Sheffield Society of Engineers and Metallurgists.**—Dr. U. R. Evans: “Thin Films on Metals”. Joint Meeting with the Sheffield Metallurgical Association. (Royal Victoria Station Hotel, Sheffield, at 6.15 p.m.)

**Institute of Welding, West of Scotland Branch.**—J. M. Baxter and H. S. Macmurchy: “Examples of Welded Fabrications for Machinery Components”. (Institution of Engineers and Ship-builders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, at 6.45 p.m.)

### THURSDAY, 15 APRIL

**Electrodepositors' Technical Society.**—Annual Conference. (Imperial Hotel, Temple St., Birmingham.)

**Institution of Mining and Metallurgy.**—General Meeting. (Geological Society, Burlington House, Piccadilly, London, W.1, at 5 p.m.)

**Royal Institute of Chemistry.**—Dr. R. P. Linstead: “The Chemical Research Laboratory, Teddington”. (The University, Edmund St., Birmingham, at 6 p.m.)

### FRIDAY, 16 APRIL

**Electrodepositors' Technical Society.**—Annual Conference. (Imperial Hotel, Temple St., Birmingham.)

### TUESDAY, 20 APRIL

**Hull Chemical and Engineering Society.**—Annual General Meeting. (Church Institute, Albion St., Hull, at 7.30 p.m.)

### WEDNESDAY, 21 APRIL

**Geological Society of London.**—Ordinary Evening Meeting. (Burlington House, Piccadilly, London, W.1, at 5 p.m.)

**Institute of Fuel.**—Dr. D. T. A. Townend: “Recent Developments in Combustion”. (Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, at 2.30 p.m.)

**Royal Institute of Chemistry, London and South-Eastern Counties Section.**—Symposium on “Laboratory Layout and Construction”. (London School of Hygiene and Tropical Medicine, Keppel St., London, W.C.1, at 4 p.m.)

## NEWS AND ANNOUNCEMENTS

### THURSDAY, 22 APRIL

**Institute of Fuel.**—Annual General Meeting, followed by the second Presidential Address by Professor C. H. Lander. (Connaught Rooms, Great Queen St., London, W.C.2, at 11 a.m.)

### SATURDAY, 24 APRIL

**Birmingham University Metallurgical Society.**—Annual Dinner. (White Horse Hotel, Congreve St., Birmingham.)

### TUESDAY, 27 APRIL

**Association of Special Libraries and Information Bureaux.**—Mr. J. C. W. de la Bere and Miss M. Dyke: "Library Liaison Officers"; Mr. James Berry: "The Information Service of the Engineer-in-Chief's Library of the Post Office Research Station". (Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, at 2.30 p.m.)

### THURSDAY, 29 APRIL

**British Glaciological Society, British Rheologists' Club, and Institute of Metals.**—Joint discussion on the Flow of Ice and of Other Solids, introduced by Dr. E. Orowan, F.R.S., and Dr. M. F. Perutz. Preceded by a film illustrating the methods of glacier research in the field as used by the Jungfraujoch Glaciological Research Party, 1938. (4 Grosvenor Gardens, London, S.W.1; film, 3.45 p.m.; discussion, 5 p.m.)

# "The Structure of Cast Iron"

by **ALFRED BOYLES** of United  
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A series of lectures with particular emphasis on the theoretical side of iron metallurgy. A great deal remains to be learned about this plebeian among metals, for the common grey iron is an alloy of great complexity and one which has been somewhat neglected by physical metallurgists in favour of the aristocratic members of the alloy domain.

The lectures are limited to the structure of cast iron as determined by the mechanism of freezing and transformation, and the argument is frankly addressed to metallurgists familiar with the steels, but unfamiliar with cast iron. Cast iron is dealt with as a ternary alloy of iron, carbon and silicon, the structure of which is modified by the minor elements, manganese, sulphur and phosphorus. Some alloying elements, added to produce specific properties, do not come within the scope of the lectures. Attention is centred for the most part on alloys of high eutectic composition, because most of the grey iron has been drawn upon and many references are cited.

The 124 pages of this book are well illustrated with figures and tables relating to the discussion, and the six chapters are subdivided into smaller groupings to explain thoroughly step by step in detail the various phases of cast-iron metal.

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## APPOINTMENTS VACANT

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**ASSISTANT METALLURGIST** for laboratory and factory development work in non-ferrous metals and alloys. Degree or equivalent qualification and one or two years' industrial experience. Age up to about 25 years. Salary according to age and experience. Reply, with outline of qualifications and experience, to Box No. 227, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

**BRITISH NON-FERROUS METALS RESEARCH ASSOCIATION—INFORMATION DEPARTMENT.** Two Assistants required—salaries up to £500 p.a. each. (a) Indexing and abstracting of metallurgical literature. (b) Information work in connection with the non-ferrous metals industry. Scientific training (not necessarily in metallurgy). Library experience or training advantageous, but not essential. Reply in writing to Secretary, 81-91 Euston Street, N.W.1.

**FURNACE TECHNOLOGIST.** Imperial Smelting Corporation, Ltd., Chief Engineer's Dept., wishes to appoint a Furnace Technologist to organize investigations into faults in existing zinc and other non-ferrous smelting furnaces and to apply the principles on the design of new furnaces. The successful applicant will work from Avonmouth, but will be required to visit other works from time to time.

Applications are invited from engineering graduates who have had appropriate industrial experience. Age limit 40 years. Commencing salary up to £750 per annum, according to experience. Contributory superannuation scheme and other conditions in line with best modern practice. 38 hour 5 day week.

Write quoting ref. JIM/FT to Manager, Personnel Dept., Imperial Smelting Corporation, Ltd., Avonmouth, Bristol, for application form, which should be returned completed by 31 March 1948.

**GOVERNMENT OF SOUTHERN RHODESIA: DISTRICT METALLURGIST, MINES DEPT.** Applications are invited for the above-mentioned post. The qualification required is a relevant University degree or equivalent professional qualification.

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Further information on interview—expenses, travel expenses, leave, &c.—and application forms may be obtained from the Secretary, Office of the High Commissioner for Southern Rhodesia, 429 Strand, W.C.2, and must be returned completed not later than 7th April 1948.

**INDEXER AND EDITORIAL ASSISTANT** required by London Metallurgical Society. Duties will involve the indexing of metallurgical literature and editorial assistance in the Publications Department: previous editorial experience is not necessary. Salary according to age and qualifications. Reply to Box No. 228, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

**LONDON METALLURGICAL SOCIETY** requires Senior Editorial Assistant (male) for its publications department. Applications are invited from graduates under 28 years of age, with a knowledge of German. Previous editorial experience is not necessary. Salary according to qualifications. Reply to Box. No. 226, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

**METALLURGICAL ASSISTANT** required for Engineering Works in North Midlands; Graduate or Associate preferred; age 20-25 years; previous experience in foundry or welding work desirable, but not essential. The post covers shop and laboratory work and offers wide scope to a man with initiative. Write stating age, experience, and salary required to Box No. 224, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

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**THE INSTITUTE OF METALS**  
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## PRESIDENTIAL ADDRESS\*

1125

By SIR ARTHUR SMOUT.†

Colonel Gueterbock, Ladies and Gentlemen,

In the first place may I say, quite simply but very sincerely, "thank you". You have called on me to succeed one of the most successful of a long line of successful Presidents—one who has worked hard for the Institute, especially during the past two difficult years of reconstruction and reorganization, and who has graced this Chair with dignity and charm. No man has had the Institute's well-being more closely at heart and, thanks to his many provincial visits, no President has been in such close contact with the rank and file of our membership.

My knowledge of Colonel Gueterbock's work and worth, while it makes me feel totally unworthy of the high office that you have conferred on me, will stimulate me more than ever to strive to justify your choice. I am inspired in this endeavour by the knowledge that, if worthy, I shall have your support and the co-operation of the Institute's officials. No man can wish for more.

## THE OBJECTS AND EARLY HISTORY OF THE INSTITUTE.

At this, the fortieth, Annual General Meeting of the Institute it would appear desirable and most opportune to re-examine the reasons which led to its establishment, the ideals its founders had in mind, and the principal objects which they intended the Institute of Metals to fulfil. From thence, perhaps, we can see how far we have achieved those objects or how short we have fallen from their ideals and objectives, and examine what steps are necessary to redeem our failings and shortcomings.

Will you bear with me, therefore, while I review our early history, analyse our first General Meeting, and recall some of the earlier difficulties and forebodings?

The Institute of Metals was founded forty years ago, after lengthy deliberations and many natural fears. The germ of the idea came from a young engineer named Walter H. A. Robertson who, in a letter dated 20 January 1908, directed the attention of the Editor of *Engineering* to the long-felt desire of progressive manufacturers "for an Institution of

\* Delivered at the Annual General Meeting of the Institute in London on 17 March 1948.

† Director, Imperial Chemical Industries, Ltd., London.

a similar kind to that valuable organization possessed by the Iron and Steel Traders". (I quote from Robertson's original letter.) The idea was quickly taken up, and Mr. W. H. A. Robertson, whom I am pleased to see present here this afternoon, may justly claim to be the initiator of the movement which led to the formation of our Institute.

A preliminary meeting of those interested was held in Manchester on 10 March 1908 (almost forty years ago to this day). Manchester, however, is proverbially a cautious City, and our forebears in the non-ferrous metals industry were cautious men; in consequence, as the proposal was then only some eight weeks old, those present were in favour of going slowly. When the Iron and Steel Institute was mooted in the early sixties, had not the founders allowed six months for the idea to germinate? An idea only eight weeks old was "an upstart"! The Victorians and the early Edwardians were not accustomed to rush their fences! The House of Commons of those days did not pride itself on crashing through legislation that would change the whole life and habits of the British people in a couple of all-night sittings! So those present at the Manchester meeting went away to think things over, and it was not until the adjourned meeting, held in London on 10 June 1908, that the all-important decision was taken. This cautious approach was just as well, for we might have been saddled with the trivial and most clumsy title of "The Copper and Brass Institute", which was at one time proposed. The second suggested title of "The Institute of Non-Ferrous Metals", although giving a more accurate description of the founders' intended scope of the Institute, was pedantic in the extreme, whereas "The Institute of Metals"—the name finally suggested—is exceedingly well chosen and will doubtless continue to endure for many years to come.

There appears to have been a fear present in the minds of all the speakers at Manchester that the new Institute might fail through the supposed disinclination of the all-powerful manufacturers to allow their technical people to contribute papers or to take part in the discussions. We were indeed "closed shops" in those days. For example, in 1908, as a student-apprentice, my then employers discouraged me from joining the new body for fear competitors would extract from my young and, I hope, receptive mind some of the so-called "trade secrets" into the mysteries of which I was being initiated. Not that my employers need have worried themselves, for at that stage in my career I was too shy to apply for membership, neither had I the necessary two guineas—a lot of money to a youth drawing 5s. 9d. a week.

Commenting on this "trade secret" complex, the *Ironmonger*, in its issue of 14 March 1908, said "The trouble in connection with 'trade

secrets' will cure itself as time goes on". How prophetic! "All but the most obtuse", continues the *Ironmonger*, "must soon be convinced that the net result of the Institute's work will be beneficial to the industry as a whole. There will no doubt always be some who will cling to a secret process, but as a general rule these will be men whose secrets are the least worth preserving." How true!

The *Manchester Guardian* of 11 March 1908, which covered the meeting of the previous day, makes interesting reading in 1948. The man who advocated caution and further consideration was Rosenhain—of all men!!! Indeed, he framed and moved the resolution advocating the desirability of a later meeting before a definite constitution was framed. It is interesting, too, to find that neither Robertson—who gave the first impetus to the movement—nor Rosenhain—the mover of the resolution—were members of the first Council. As they were both under forty years of age, they would doubtless be rated as too raw and inexperienced by the doyens of those days.

In addition to Sir William White, whose Presidential Address was a masterpiece of clear, concise English, setting forth the objects of the Institute and its ideals, there were among others on the first Council such men as Norman Cookson, Gowland, Gerard Muntz, Engineer Vice-Admiral Oram, Thomas Turner, Boedicker, Tom Bayliss, Carpenter, Nisbett, and Dr. R. S. Hutton, and we should not overlook the pioneer work of W. H. Johnson of Manchester, the first Honorary Secretary. "There were certainly lions in those days!" Alas, all have passed over with the exception of those pioneers of scientific industrial metallurgy, Thomas Turner and R. S. Hutton.

I would also make more than a passing reference to Shaw Scott, Birmingham's first graduate in metallurgy, a keen young man, full of the energy of youth, who was our first Secretary and Editor, and to whose guidance and devotion we owe so much. I am amazed at the high standard Shaw Scott set from the very first issue of the *Journal*, with its full report of the proceedings and discussions and its abstracting service, especially when I recall this was virtually a solo effort. I can see him now, when as a student-apprentice I was attending a course of the Professor's lectures, housed in the gallery at Edgbaston with no equipment other than a desk, a chair, a typewriter, and a file. These were the conditions under which the Institute was cradled and our first *Journal* produced. Only the enthusiasm of youth, fired by an almost fanatical devotion to duty and a grim determination to command success, could possibly have steered us through those early formative years.

Ladies and Gentlemen, it is well to recall those days, and to

pay tribute to those pioneers at this, our fortieth, Annual General Meeting.

The papers read at the opening meeting in Birmingham in November 1908 make most interesting and informative reading, even to-day, and one cannot but be impressed with the range of subjects discussed, and the strong feature made of papers dealing with the manufacturing side of the work of the Institute. Milton, the Chief Engineer Surveyor of Lloyd's, gave his experience as a user of copper and copper alloys; Bengough and Hudson—two bright young things who were to leave their mark on the industry over the years to come—discussed the mechanism of annealing copper alloys; Echevarri spoke of aluminium and its uses, and referred to the enormous demand for aluminium in 1906 and 1907 (the word "enormous" related to the world production of 15,000 and 23,600 tons, respectively. Little could he have dreamed of the 1,890,000 tons produced at the peak of the war usage; a hundred-fold increase during the lifetime of this Institute: no wonder the light metals loom so large in our transactions). Arnold Phillips, the Admiralty Chemist, related the experience of His Majesty's Navy with phosphor-bronze. Walter Rosenhain, who had just taken charge of the Metallurgical Department of the National Physical Laboratory, made the first of what the President hoped would be "a series of communications based on the work done there"—a hope well founded. Desch, who at that time was engaged in writing one of the pioneer text-books on metallography, was there. He gave a contribution on "Inter-Metallic Compounds" which presented to members, in concise form, much valuable research work in a field quite unexplored by the average member of those days, and in a language that was "double-dutch" to the manufacturers and also, I expect, to many of the technicians. And so, in order to give the poor Birmingham manufacturer a chance to come down to earth after the learned discourses of Rosenhain and Desch, Walter Robertson wound up the meeting with a characteristically practical paper on the manufacture of tubes. Gerard Muntz described it as rather like "bringing coals to Newcastle to read a paper on tubes in Birmingham". Birmingham evidently knew all there was to know, and the wise old President inveigled Muntz into the promise of a Paper at a future meeting. Norman Cookson concluded the discussion with the comment "The research man should stick to his last" and that "he would be doing very much more good in that way than in attempting to solve manufacturing difficulties in the application of his ideas".

We've moved, thank goodness, in the past forty years. I am not jibing at Cookson; he was typical of his times, and I quote him merely

because his words perhaps epitomize more than anything I can say the manufacturer's attitude towards science and research in those days. They certainly show the yawning chasm of ignorance and prejudice the Institute has had to bridge in order to bring scientists and practical men engaged in works operations into that close contact we enjoy to-day. This the Institute has done, and in so doing has probably registered its most important achievement over the years of its existence.

#### THE FUTURE ROLE OF THE INSTITUTE.

So much for the past and our genesis. What of the future? Personally, I am only interested in the past in so far as it provides a lesson and a stepping-stone for the future. To quote William Conolly, "We should so live and labour in our time that, what came to us as seed may go to the next generation as blossom, and that which came to us as blossom should go to them as fruit".

When considering the preparation of this Address, I asked myself "What is the role of the Institute of Metals; what part can it best play to-day in the development of the art and science of metallurgy? What contribution can it make towards the well-being of mankind—towards the building of a better Britain?"

Progress in all branches of learning is largely dependent on the full interchange of knowledge among workers pursuing similar lines of study. Metallurgy is an old art and a new science. As a Director of a large company, whose metallurgical interests—though the largest in Europe—are small by comparison with its chemical interests, I am perhaps in the unique position of being able to contrast the two industries, and particularly the scientific approach and the works technique characteristic of the two industries.

It is the duty of those of us engaged on the industrial side to make a continually improved product at a continually reduced cost of production available to the user, and, through him, to the general public, passing on to the ultimate consumer most of the benefits to be derived thereby. This is the means by which the standard of living of our people can be permanently raised. How is this to be done? I believe the important factor is "continuity of production", and here I cannot help but contrast works processes as carried out in the chemical industry with those in the metallurgical field. The great chemical industry is essentially based on continuous processes operating 365 days a year, 24 hours a day. The manufacturing metallurgist and the user work, in the main, on batch processes, nowadays operating a five-day week; no wonder capital investment per ton/year plays so large a part in our

considerations ! Up to now we have striven to combat this by speeding up our motors, rolling mills, wire drawing machines, presses, &c., and as metallurgists we have solved the problem of materials which will stand up to these increased demands; but I suggest this is merely toying with the problem.

The best method of increasing production and obtaining the maximum return from the capital employed is the decrease, or the complete elimination, of "idle time" rather than in trying to increase speed *per se*. It is self-evident that if our metallurgical plants must start, operate, and stop, to produce a product, not only will the efficiency of the plant be increased by eliminating the starting, stopping, and stand-still time, but the resultant product will be greatly improved if it is produced by a continuously uniform operation. Its cost, too, will be lessened even if the actual speed of the machine when operating continuously is lower than the speed of the machine in the first instance. This question of elimination of idle time, this all-important matter of continuity of operations is, I suggest, a major lesson we in the metals industry can learn from the industrial chemist. It is certainly one which strikes me most forcibly when I contrast operations in a great chemical works, such as Billingham, with our so-called modern and by no means insignificant metal factories in Birmingham. Admittedly, the industrial metallurgist can point with pride to the improvements made in production processes along the lines of eliminating waste or idle time, to continuous methods of casting, to the so-called continuous rolling on tandem mills, and to continuous wire-drawing technique, &c. All of these are developments of recent years, but the fact remains that continuity of operations is not a strong feature of the metals industry generally. We are, by and large, a "batch process" industry, and to any industrial metallurgist laying out a new plant I would commend the technical approach of the industrial chemist as worthy of close consideration. There is much to learn.

The metallurgical industry is as old as Tubal Cain himself, whereas as Hume-Rothery \* has pointed out "much of the chemical industry of to-day is a large-scale development of previous laboratory research and the industry has developed *after* the main principles of chemistry have been established". On the other hand, we metallurgists always seem to be trying to explain things which have been practised over many years; we are attempting to superimpose a science on an old-established art. This gives rise to its own peculiar and special problems, both in the field of research and in works practice.

We members of the Institute of Metals are trying to collect facts,

\* "Researches on the Structure of Alloys," *B.N.F.M.R.A. Report No. 562.*

to analyse them, and to interpret them in terms of works technique. The proper collection of these facts, which has always formed an important part of the Institute's work and has been a prominent feature of its *Journal* and other publications, is the stepping-stone to future knowledge and the permanent aid to generations of workers yet unborn. And so, although I belong most definitely to the school of industrial metallurgists—those who are trying to apply and adapt scientific knowledge to works practice—I would plead with members, as I have done on other occasions, to encourage those who are engaged on investigations which may at present possibly be of little or no commercial value, but are calculated to establish the underlying general principles of the science of metallurgy. It is no exaggeration to say that the whole of our vast chemical industry, both inorganic and organic (and here I include the country's rapidly growing pharmaceutical interests), is based on principles revealed only as the result of arduous work on substances originally of academic interest only.

Again I quote Hume-Rothery \*: "The development of physical metallurgy has been very different, since here, traditional practices have been handed down through the ages and it is only in comparatively recent times (and, I might interpolate, mostly within the life of this Institute) that scientific methods have been used".

"It should be appreciated", continues Hume-Rothery, "that, scientifically, there is nothing more improbable in the idea of building up an alloy of desired properties from a knowledge of the characteristics of the different kinds of atoms, than there is in building up synthetic dyestuffs with desired colours. The difference between the two problems lies, largely, in the fact that whereas the dyestuff chemist works with a soundly established science behind him, in physical metallurgy the general principles are only just being revealed."

Metallurgy too is not without its parallels. Most of our modern non-ferrous alloys, many of which played so important a part in the war effort, have been built up deliberately, not as the result of numerous trials and errors as in the past, but on general scientific principles well established by investigators in the so-called academic field. The aluminium light alloy which formed the basis of our aircraft construction programme is a practical instance, and many others could be cited did time permit.

The progress of all science is essentially a cumulative one; we build our work on the foundations established by our predecessors. This Institute is a learned society; it is not a research association. We exist to collect facts, to exchange ideas, to disseminate and record

\* *Loc. cit.*

new knowledge, and to build up works technique and user practice on the information and experience thus acquired. It is all the more important, therefore, that those of us who are concerned with the practical application of metallurgy should encourage on every hand those of our colleagues who are engaged in seeking new knowledge, and should see that every possible step which lies within our power is taken speedily and scientifically to adapt this knowledge to industry.

That is not always quite so easy as it may appear at first sight. As Barclay pointed out during the course of his Presidential Address in 1936, " Works' practices are necessarily complex, if only in the sense that all industrial processes are carried out under composite conditions ". They embrace such factors as the impact and reaction of labour, economic conditions, financial considerations, &c., whereas as Rosenhain \* has stated, the scientific investigator rightly endeavours to simplify his conditions so far as possible. " How " is generally a much more complex problem than " why ".

I recall when I was younger I had the firm conviction that the higher management was singularly dumb and unappreciative of things that seemed to me to matter so much. Since I myself have reached that estate I am inclined to believe my earlier convictions were not entirely ill-founded, but, on the other hand, I now realize that higher management is faced with problems which are in many ways far more difficult than those of the research worker and the technician ; the latter deal with recommendations, the higher management have to make decisions, and when mistakes are made and errors of judgment committed there is no alibi for them—the evidence stands out too markedly and too distinctly. I would ask our technical members, therefore, to be merciful to higher management when, without adequate tangible proof, it will not follow quite so far nor so fast as some would like it to do. Higher management and the much abused industrialist are not necessarily hostile nor unappreciative. There may be circumstances which prevent immediate action, or at any rate, action for the time being. Let not this discourage the technician from pressing on, for sooner or later management will, and indeed must, as a matter of good business, support sound recommendations based on knowledge, or go under.

#### THE RESPONSIBILITIES OF MEMBERS AND LINES OF FUTURE PROGRESS.

Members owe a duty to the Institute, to enhance its prestige and make it more representative of the industries that it serves ; to be

\* *J. West Scotland Iron Steel Inst., 1915-16.*

active, and maintain a lively and progressive attitude to the Institute's affairs; to attend its meetings and participate in its discussions; and to make their own contributions to the literature. The more we contribute to the Institute, the more we shall get out of it. I hope every member will seriously consider how best he can strengthen the Institute of Metals and help it to attain the objects for which it was founded.

I am certain there are many worth-while subjects on which members could write with advantage, especially those dealing with works technique and practices and the adaptation of scientific principles to the metallurgical industry.

Of recent years—as in the past—there have been complaints that the Institute has not published more so-called “practical” papers, but the remedy lies entirely in the hands of the members themselves. I do not think we can any longer complain of the reticence of management to permit the publication of such matter dealing with works technique. Management will usually encourage this by granting time and facilities, and members and works technicians especially should not be backward in submitting contributions in this field. In this connection the Council welcomes, as I am sure will members generally, the generous scheme recently sponsored and financed by Messrs. Capper Pass and Son, Ltd., and for which we owe so much to the personal interest and inspiration of our immediate Past-President—Colonel Gueterbock.

In an endeavour to adjust the balance of things, it is the Council's intention that in 1949 a whole day shall be devoted to a Symposium or General Discussion on the subject of metallurgical aspects of non-ferrous metal melting and the casting of ingots for working, to which leading technicians will be invited to contribute. It is hoped at this meeting there will be a full, practical discussion on a subject of great interest and importance to all members, and that this experiment will lead to the establishment of a regular series of critical examinations of various aspects of works practices, to the advantage of our members and the advancement of British industry. I therefore look forward to that particular meeting with exceptional interest.

During the past forty years the Institute's literature is rich in good sound thinking and in the study of basic fundamental work. The time has now come, and indeed is overdue, when, in order to assist in the production of better materials at competitive costs or the same materials at lesser costs, we should give equal thought and prominence to the practical application of this fundamental knowledge. This is surely one of the Institute's proper functions in relation to our industry. It is one which our founders certainly had in mind, even if in recent

years we may not have developed it as strongly as some of our members feel—and perhaps rightly so—we should have done.

The Non-Ferrous Metals Industry, for which this Institute stands as the accredited learned society, covers a wide field; but fortunately the knowledge acquired, collected, and disseminated by the Institute is capable of application over an equally wide, if not wider field. Thus, our meetings, discussions, and publications are of material interest to all members, regardless of the particular product they manufacture or use, or the pet scientific problem they have under review at the moment. The value of the Institute's work is perhaps greatest to those user and manufacturing members who, either by virtue of their own knowledge or the knowledge of technical men in their employment, are most capable of understanding it and of grasping quickly and clearly its implications and significance in relation to the day-to-day problems facing the industry on the production side.

I suggest the ordinary member should resist the temptation to say "that is of no interest to me; I am not interested in the manner in which different kinds of atoms occupy a common lattice". Let us so-called practical men beware of such a narrow and detached attitude, for herein may lie the solution of one of our most pressing problems. If the language of the scientist is beyond our comprehension, and I admit, so far as I personally am concerned, much of it is, then it is up to us to see that as industrialists we have on our staffs technical men with wide vision and great adaptability who have been trained to grasp the full significance of such observations. We must give them facilities for keeping in touch with the latest research, even of the most abstruse kind, and enable them to interpret it to works practice for us. To our scientist colleagues I would say: "We want your theories and your ideas, if they are good and have real application to the problem at hand".

The great appeal of the Institute of Metals to me lies in the fact that it supplies such an important link between higher management engaged in the problems connected with our industry, and the scientist and technician searching for fundamental knowledge and its applications.

During my period of office it will be my endeavour to strengthen this link, for I believe that therein lies the strength of our industry and the keystone upon which further progress will be built. It is on these grounds that I appeal to members of all classes—the scientist, the manufacturing metallurgist, and the user—to afford our Institute every support—not merely financial, but also by active personal interest. Financial support is, however, important if we are to carry on our existing services and meet the improvements demanded by the

present rapid developments of metallurgical science. Your Council wants not only a largely increased membership, but, as I have said earlier, an even more lively interest taken in the affairs of your Institute by each and every member.

As I was completing the draft of this Address the Secretary called my attention to some remarks of Dr. Rochester of the University of Nebraska (U.S.A.) regarding membership of professional societies.

Dr. Rochester is reported as saying :

“ I do not recall that I have ever known a person who has stood high in his business or profession who has not actively affiliated himself with organizations, attended meetings, and read magazines connected with his affairs. These seem to be the ways in which people keep up to date and alert to the new things which are going on. I should dislike to trust myself or a member of my family to the care of a physician who does not belong to a medical association, who does not read professional journals, nor go to professional meetings. I would equally dislike to think that my child is being taught by a teacher who has not sufficient interest in her work to secure the information and inspiration that come from such activities.”

#### CONCLUSION.

I have this morning, on this our fortieth anniversary meeting, endeavoured not only to look back, but also to look forward. I have tried to trace our earlier history and to outline some of our achievements. I have, I hope, not hesitated to name some of our shortcomings. I have tried to show what we owe to the pioneers and seekers of fundamental truth and knowledge, and to trace the part the Institute has played in the bringing together of research and technical application on the one hand, and the metals industry on the other, and how the trained metallurgist has applied and can apply scientific principles to works technique. But I shall have failed in my object if I have stressed how great we are; rather would I emphasize how great we might be, and what a contribution all grades of members have still to make to the science of non-ferrous metals and to the industry to which we owe so much. Every man is a debtor to his profession.

Members of this Institute are occupying positions of increasing importance; their influence on our national life is growing daily. May we, one and all, rise to the occasion and while glorying in, and deriving inspiration from, the Institute's record over the past forty years, press on to a greater achievement of the objects for which the Institute was so wisely founded by our predecessors.



# THE MEASUREMENT OF THE DAMPING **1126** CAPACITY OF METALS IN TORSIONAL VIBRATION.\*

By G. A. COTTELL,† K. M. ENTWISTLE,‡ M.Sc., and PROFESSOR F. C. THOMPSON,§ D.Met., M.Sc., MEMBER OF COUNCIL.

WITH AN APPENDIX ON

## THE ESTIMATION OF SPECIFIC DAMPING CAPACITY FROM MEASUREMENTS OF EXPERIMENTAL DECAY CURVES.||

By G. L. J. BAILEY,¶ Ph.D., MEMBER.

### SYNOPSIS.

The cause of the discrepancy between the results of "mechanical" and "physical" methods of measuring damping capacity in torsional vibration has been investigated. It has been found that in the case of a machine of the Föppl-Pertz type, as hitherto constructed, the energy loss in the machine itself may, when testing a material of low damping capacity such as Duralumin, amount to about 500 or more times the intrinsic energy dissipation of the specimen. All the major sources of loss have been isolated, and complete re-design of an existing machine has reduced the measured damping to the order of twice the lowest values measured by the physical method. The use of a solid of revolution in place of the usual rectangular bar as the oscillating inertia has been found to be essential. The air-friction energy loss over the surface of the oscillating wheel was measured in order to determine the air-loss correction to be applied to the test results. This latter work necessitated the construction of a small machine for tests at reduced air pressures. The damping capacity of Duralumin as measured with this machine was found to be in excellent agreement with the lowest determinations by physical methods.<sup>1</sup> This investigation confirms that the physical and mechanical methods are in fact measuring the same property, and shows that, at any rate for aluminium alloys, results of the same order can be obtained by the two methods, provided that the apparatus is designed correctly.

In Appendix III to the paper, a method of treating experimentally-recorded decay curves is proposed which permits the estimation of the specific damping capacity at any measured amplitude, within calculable limits of error.

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## I.—INTRODUCTION.

THE damping capacity of a solid is a measure of its ability to dissipate vibrational energy. In the field of metallurgical research, it has been thought for some time that the measurement of the damping capacity of metals might give sensitive indications of structural changes and thus might be developed into a quick and non-destructive quality-control test. Recent work has confirmed this view; Zener,<sup>2,3</sup> for instance, has shown that the measurement of damping capacity can, under certain conditions, give an indication of the relative grain-size, while Hanstock and Murray<sup>4</sup> have developed a technique which the former<sup>5</sup> has used to correlate the variation of damping capacity during vibration with the onset of fatigue.

The methods used for the measurement of damping capacity may be divided broadly into two categories, which have been designated, perhaps not altogether justifiably, "mechanical" and "physical". Considering the particular case of torsional vibration, the physical method uses a specimen in the form of a uniform cylindrical bar which vibrates in the "free-free" mode, while in the mechanical method the frequency of vibration is much reduced by fixing two inertia masses on the ends of the specimen. The latter is the basis of the design of the well known Föppl-Pertz machine.

A comparison of the results obtained by the two methods of measurement showed that, for low damping materials such as Duralumin, the mechanical methods gave a value for the damping capacity a hundred or more times that determined by the physical methods. It was the general opinion that this might be attributable to the much higher stresses used in the Föppl-Pertz-type machines, but the development by Hanstock and Murray<sup>4</sup> of an ingenious apparatus which enabled high stresses to be attained at a much higher frequency, showed that the order of the discrepancy was not seriously changed when results were compared at the same stress.

The only other fundamental variable was frequency. Bearing in mind the essential similarity of the two methods and also the fact that damping capacity is not seriously affected by the test frequency in either the range of the physical or the mechanical methods (an assumption for which there is some experimental justification<sup>1,6</sup>), there seemed, at the time this research was in contemplation, no *a priori* reason why both should not give results of the same order of magnitude when similar materials were tested.

It has already been established that damping capacity is a highly sensitive property which is capable of being influenced considerably by

small changes in the treatment and past history of the material.<sup>7, 8, 9, 10, 11</sup> While this sensitivity may serve to explain differences in measured values of a minor order, it is totally inadequate to account for the discrepancy between the mechanical and physical determinations as shown by published results. Either there was a serious error in one of the methods of measurement, or the two were measuring different properties, or there was a marked frequency sensitivity. The primary object of this research was to establish which of these factors was responsible for the difference between the results obtained by the two methods.

The work referred to in this paper was carried out individually by one of the authors (G. A. C.) up to the point when all the major sources of error had been eliminated from what is described as the "large" machine, and a "small" machine had been designed and constructed for the measurement of air-friction energy losses. At this stage, it became necessary to carry out some tests by a physical method for comparison purposes. One of the authors (K. M. E.) was engaged at this time on a parallel research involving the use of a physical method and was thus able to undertake this part of the investigation; the two research programmes were then merged, and the final stages of this work, including the air-friction energy-loss determinations, became a joint enterprise.

In order to show in a convenient manner the progressive decrease in the measured damping values obtained as the various machine losses were successfully eliminated, the more important test results have been plotted on one diagram (Fig. 1), using a logarithmic ordinate scale; a few points indicate the order of results obtained by some other workers.

## II.—CALCULATION OF RESULTS.

All the results quoted in the paper are expressed in terms of the specific damping capacity,  $P$ , which is defined by the relation :

$$P = 100 \times \frac{\text{vibrational energy dissipated by internal friction per cycle}}{\text{vibrational energy at the beginning of the cycle}} \%,$$

where the vibrational energy at any instant is the sum of the kinetic and elastic energies.

In the earlier work, the results were calculated by the relation :

$$P = \frac{400}{n} \left( \frac{A'_1 - A'_{n+1}}{A'_1 + A'_{n+1}} \right) \%,$$

where  $A'_1$  and  $A'_{n+1}$  refer to the double amplitudes of the first and

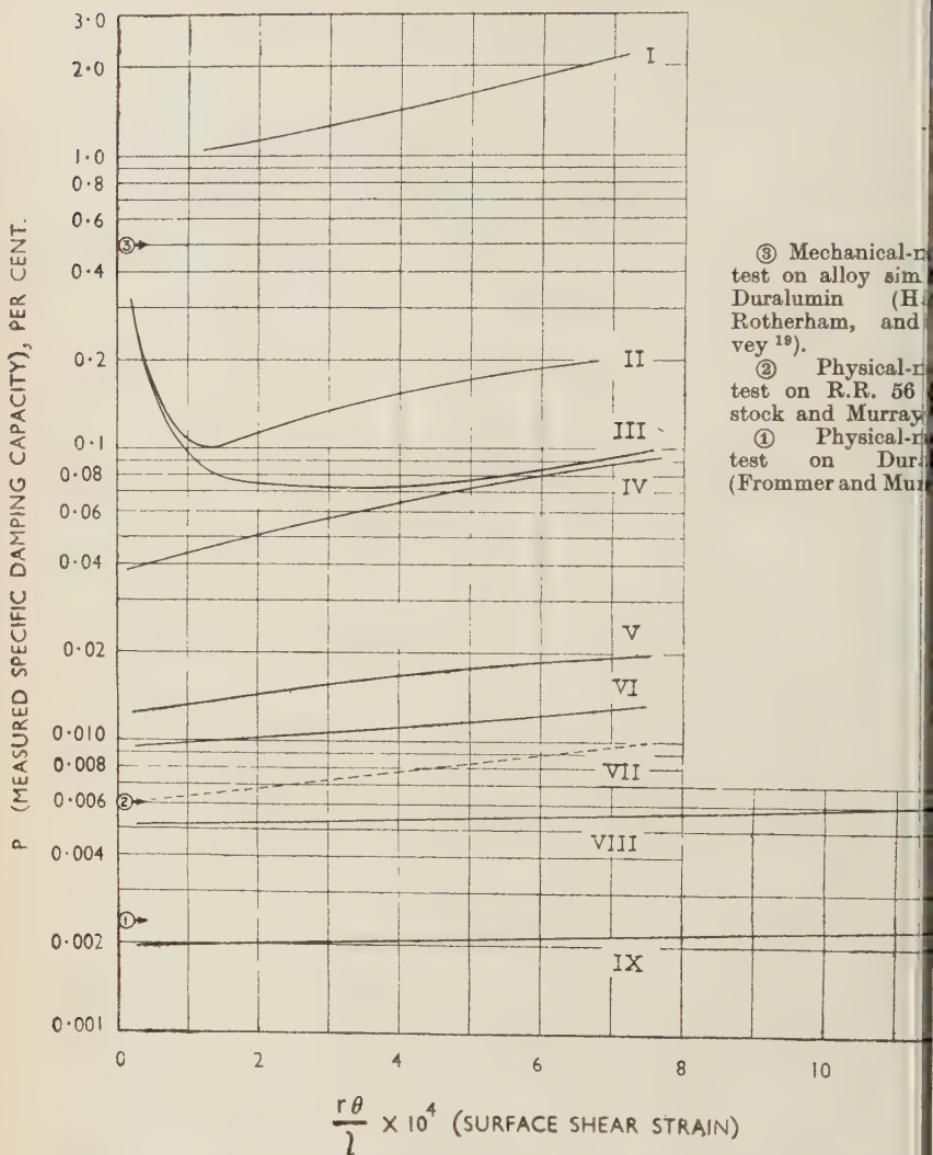


FIG. 1.—Curves Showing Progressive Decrease in Measured Damping Capacity.  
(N.B.—The logarithmic ordinate has distorted the shape of the curves.)

For Key, see p. 377.

③ Mechanical-m test on alloy sim Duralumin (H. Rotherham, and vey<sup>19</sup>).

② Physical-m test on R.R. 56 stock and Murray

① Physical-m test on Dur (Frommer and Mu

$(n + 1)^{\text{th}}$  cycles, respectively—see Fig. 2. This expression was adopted in order to enable the results to be compared directly with those of other investigators who had used this expression.

In all the work following the substitution of the wheel for the rectangular bar in the large machine, a basis of calculation involving a smaller approximation error was adopted, i.e. :

$$P = \frac{200}{n} \log_e \left( \frac{A_0}{A_n} \right) \%,$$

where  $P$  is the average specific damping capacity in the interval during which the semi-amplitude falls from  $A_0$  to  $A_n$ . The approximation error arising from the use of this expression never exceeds 0.01% of the value of  $P$  for any of the results obtained with the small machine given in this paper.

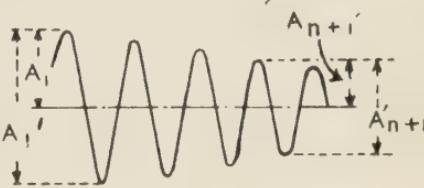


FIG. 2.

The strain-damping characteristics were obtained by plotting the values of  $P$  so obtained against the mean amplitude during the interval, i.e. :

$$\frac{A_0 + A_n}{2}$$

The magnitude of observational errors is discussed in Appendix II.

Some aspects of the treatment of amplitude-decay measurements are discussed by Dr. G. L. J. Bailey, Head of Physics Section, British Non-Ferrous Metals Research Association, in Appendix III.

#### KEY TO FIG. 1.

- I. R.R. 56. Specimen 0.4 in. dia.  $\times$  2 in. test length, with square shanks.  
Tested in original machine prior to any modifications.
- II. R.R. 56. Specimen as I above, tested after reconstructing machine frame.
- III. R.R. 56. Above-mentioned specimen modified by machining away square shanks to obtain continuous test length between grips of 0.4 in. dia.  $\times$  6 in.
- IV. R.R. 56. Specimen as in III, tested with steady-bearing out of action.
- V. R.R. 56. As IV, except wheel substituted for rectangular bar as inertia member.
- VI. Duralumin. Specimen 0.4 in. dia.  $\times$  6 in. test length. Conditions as V.
- VII. Curve VI corrected for calculated air-friction loss over wheel.
- VIII. Duralumin. Specimen 0.312 in. dia.  $\times$  6 in. test length, with taper cylindrical shanks expanded into grips. Small-wheel inertia member.  
(Tested in large and small machines with identical results.)
- IX. Specimen as VIII, tested in small machine at low pressure (0.004 mm. mercury.)

## III.—MODIFICATIONS TO ORIGINAL MACHINE.

The first mechanical machine for the measurement of damping capacity in torsional vibration was installed at the Wöhler Institute at Brunswick. It was designed by Pertz,<sup>13</sup> subsequently modified by

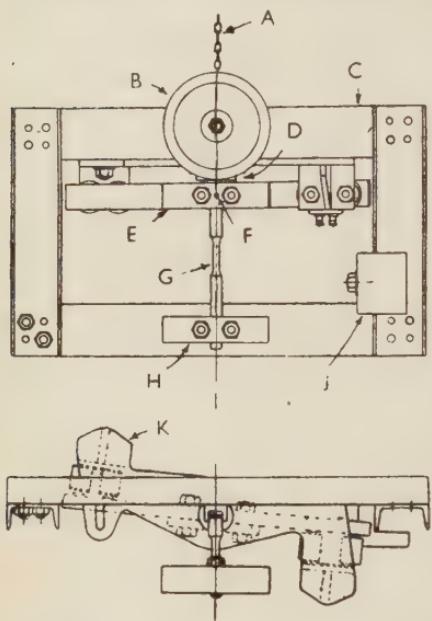


FIG. 3.—Sketch of Original Machine.

## KEY.

- A. Suspension chain.
- B. Balance weight.
- C. Bolted channel frame.
- D. Ball bearing.
- E. Oscillating bar.
- F. Mirror (camera not attached to frame).
- G. Specimen.
- H. Bottom grip.
- J. Balance weight.
- K. Electromagnetic release on adjustable bracket.

same order as those obtained with other machines of similar basic design. During the course of the investigation, this machine has been completely redesigned and reconstructed; the various parts were discarded or modified, and new parts of different design substituted as the progress of the investigation dictated. The final result was the virtual disappearance of the original machine except as a convenient source of material for reconstruction purposes.

Knackstedt,<sup>14</sup> and was used extensively by Föppl,<sup>7</sup> who has described it fully. It is generally known as the Föppl-Pertz type of machine. Several workers in the damping field have constructed machines incorporating the essentials of the Föppl-Pertz design, but differing to some extent in the details of construction, namely Contractor and Thompson,<sup>15</sup> Hatfield, Stanfield, and Rotherham,<sup>16</sup> Canfield,<sup>17</sup> and Norton<sup>18</sup>; the Cambridge Instrument Co., Ltd., also has marketed a machine of this type which does not conform to the Föppl-Pertz design so closely.

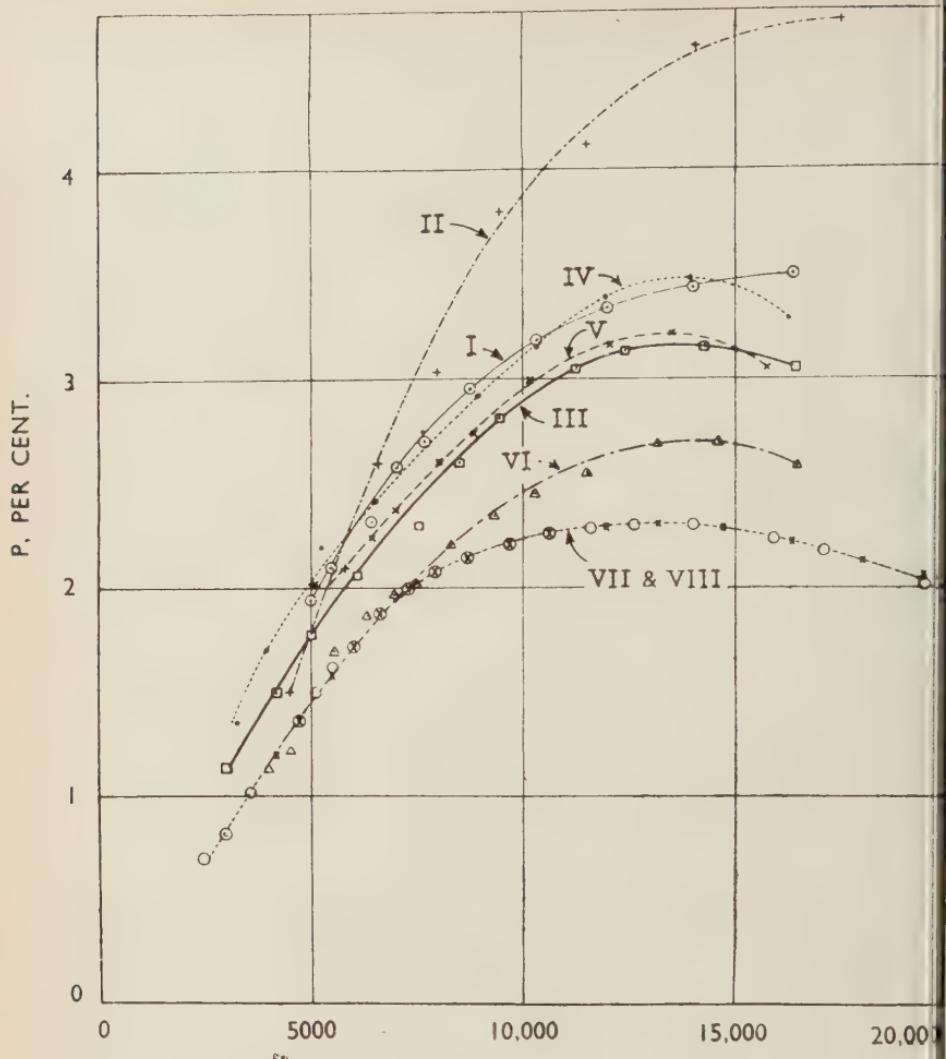
At the time this work was begun, the original machine used by Contractor and Thompson,<sup>15</sup> and subsequently by Stanton and Thompson,<sup>12</sup> was available, and it was decided to make use of it as a basis for the experimental work. There were obvious advantages in employing a machine which had been used for previous work and was known to be capable of giving results of the

The construction of this particular machine and the method of recording the amplitude decay have been fully described by Contractor and Thompson<sup>15</sup> and are shown in Fig. 3. Preliminary tests on the original machine showed the need for alterations to the optical recording system, and this was considerably modified, as shown in Fig. 6. The relation between the width of the record and the angular strain in the specimen represented by it was obtained by means of two dots, one corresponding to the equilibrium position of the inertia and the other with the latter deflected through a measured angle. This procedure compensated for any change in the dimensions of the paper as a result of processing.

### 1. *Modifications to Grips.*

As the efficacy with which the specimen shanks are gripped is clearly of fundamental importance, this was the first matter to receive attention. The original form of grip consisted of two 90° "V" blocks for the reception of the square shank of the specimen, which was clamped over the full 2-in. axial length of the grip faces. It is impracticable to ensure satisfactory mating of the grip-specimen shank faces over such a large area, even with very accurately prepared surfaces; the interfacial pressure varies from nil in one area to a maximum in another, and relative movement may occur between the grip and shank faces where the pressure is low, with consequent friction and dissipation of energy. This friction will vary with the form of the mating surfaces and the degree of tightening of the grip bolts.

Curve I, Fig. 4, shows one damping characteristic, for a steel specimen, with the machine in its original condition, while curve II indicates the change resulting from rotating the specimen through 90° and re-gripping, all other factors remaining unchanged. It was found impossible to remove and replace a specimen and still obtain reproducible results when using the original grips. This defect was overcome by reducing the area of the grip faces to a point where the intensity of the interfacial pressure resulted in slight plastic deformation of the specimen shanks, thus eliminating areas of light contact pressure. In the initial tests, this was done by inserting thin steel packers between the grips and shanks, and the result of doing so is indicated by curve III, Fig. 4. Ultimately the packing pieces were discarded and the grip faces cut away as shown in Fig. 5, bolts with fine threads being substituted for the standard Whitworth bolts in order to obtain the required interfacial pressure with less manual exertion. Throughout all the subsequent tests no difficulty has been experienced in obtaining reproducibility of test results when using this relieved form of grip face;



NOMINAL SURFACE SHEAR STRESS, LB. / SQ. IN.

FIG. 4.—Tests on Original Machine. Mild steel, 0.2% carbon. Specimen 0.4 in. dia.  $\times$  2 in. test length, with square shanks.

## KEY.

- I. Unmodified machine.
- II. Specimen removed, rotated 90°, and replaced.
- III. Packing pieces inserted between grip faces and specimen.
- IV. Frame-joint bolts slightly loosened.
- V. Frame-joint bolts retightened.
- VI. Grip faces modified, B.S.F. thread grip bolts fitted and inertia member balanced statically.
- VII. Machine frame completely reconstructed, camera not affixed to frame.
- VIII. As VII, but camera affixed to frame.

various specimens have been removed repeatedly between tests and the results always found to lie within the limits of experimental error when the test conditions were identical.

## 2. *Modifications to Machine Frame.*

Having developed a method of gripping which enabled a specimen to be removed and replaced without affecting the measured damping, attention was turned to the machine frame. This was very obviously deficient in rigidity, the method of fabrication being such that relative movement at the joints was to be expected. With a view to ascertaining the order of the losses thus introduced, further tests were carried out; the specimen used for the grip tests was employed and the results are shown in Fig. 4. The first test showed good agreement with curve III. The frame corner joint bolts were then eased off very slightly, and a further test showed that the measured values of the damping had increased considerably, as shown by curve IV; on re-tightening the bolts, the test results reverted to the original order, as indicated by curve V, the slight change in values being due, presumably, to the frame joints having been disturbed. It was thus confirmed that bolted corner joints were a potentially serious source of error and should be avoided.

During other tests carried out at this stage with a view to assessing the amplitude of vibration of the frame, it was observed that a point near the support traced a small ellipse. This motion was found to be due to lack of balance of the inertia member, whose centre of gravity was not coincident with the specimen axis. To remedy this defect the inertia member was balanced statically, the results of a test made after this alteration had been carried out being shown by curve VI, Fig. 4. It will be seen that the measured damping values have decreased substantially; it was also found that the elliptical motion of the frame no longer occurred.

It was considered impracticable to obtain satisfactory results by mere modification of the frame, and complete reconstruction was therefore decided upon. The more-important considerations which determined the design of the new frame were as follows :

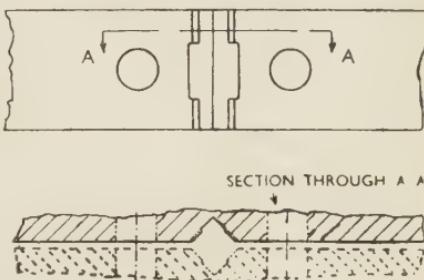


FIG. 5.—Sketch Showing Modified Grip Surfaces.

(1) Measurements had shown that the amplitude of vibration of the frame was excessive, as it was of the order of 10% of that of the inertia member.

(2) Maximum rigidity was obviously essential, and with this end in view the new frame was designed as a welded structure, with a minimum number of bolted joints.

(3) The existing steady-bearing housing had no provision for radial adjustment of the position of the bearing, which was also constrained axially. Facility for adjusting the bearing position was clearly necessary.

(4) A feature present in all the early tests carried out with this machine was a large loss of amplitude during the first half cycle. This was found to be due to the use of electromagnets for retaining the inertia member in the deflected position, and was eliminated by removing the magnets and substituting a mechanical form of release.

(5) If a specimen is to be clamped securely, considerable force must be used in tightening the grip bolts, and unless the inertia member can be held during this operation, there is a danger of bending the specimen. Provision was made for anchoring the inertia member to the frame.

(6) Subject to the moment of inertia of the new frame being increased substantially, it was considered feasible to attach the recording camera to it. The advantages of doing so were: (a) the record would show the relative motion of the inertia member and frame instead of that between the inertia member and a point outside the system, (b) the tedium of bringing the machine completely to rest prior to starting a test would be avoided, and (c) the need for carrying out tests in darkness would be obviated.

The foregoing considerations, among others, resulted in the design of frame shown in the drawing of the general arrangement of the machine as it appeared at this stage, Fig. 6. A massive steel ring (1) (actually a tyre forging) formed a rigid base with a high polar moment of inertia, and to this was welded a superstructure (2) consisting of part of the original frame, the corner joints of the latter being reinforced by welding. The lower grip assembly comprised a central disc of high-carbon steel (3) cut away at one side for the reception of a movable section (4), the two being pulled together by means of the bolts (5) to form the grip; the grip faces were relieved in the manner already described. The disc was welded into a diaphragm plate (6), the periphery of this being welded to the inner circumference of the base ring. Tubular steel struts (7) were welded into position to impart rigidity to the superstructure. The steady-bearing housing (8) was modified to

provide radial adjustment and axial freedom of the bearing. A steel suspension cable (9) was used in place of the chain.

The original rectangular-bar inertia member was used, the only modification being the provision of two small welded-on lugs (10) for

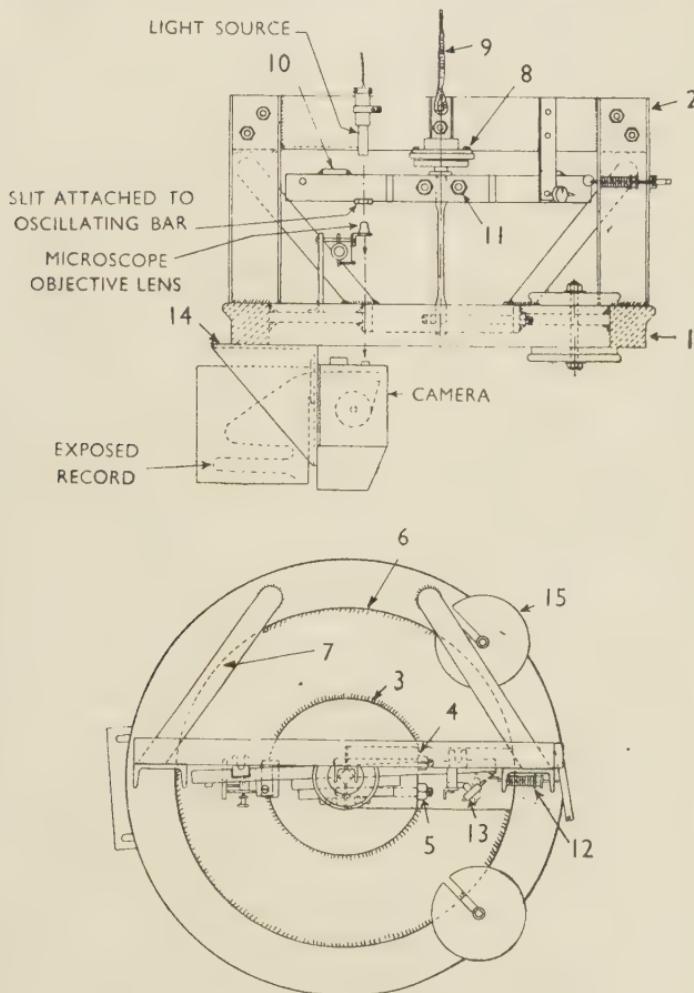


FIG. 6.—Sketch of Partly Reconstructed Machine.

the purpose of anchoring it when tightening the grip bolts (11). The bar was retained in the deflected position by means of a mechanical trigger gear (12), which was capable of adjustment to cover the amplitude range required. The setting of this was made with the aid of the dial-type micrometer (13), which could be swung into position when needed. A substantial welded bracket (14) was provided for the

attachment of the camera. Balance weights (15) enabled the axis of the specimen to be brought into the vertical position.

On completion of the work of reconstruction described above, the steel specimen used in the previous series of tests was inserted in the machine and tested, the result being shown by curve VII, Fig. 4.

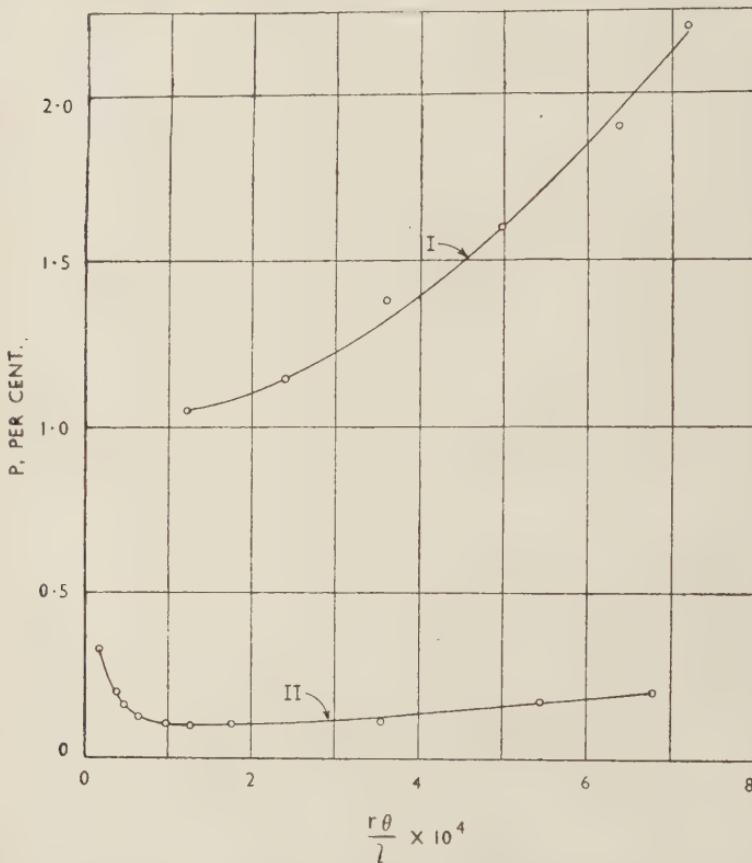


FIG. 7.—Curves Showing Effect of Reconstructing Machine Frame. R.R. 56 specimen 0.4 in. dia.  $\times$  2 in. test length, with square shanks.

KEY.

- I. Tested in original machine prior to any modifications.
- II. Tested after modifications to machine frame were completed.

The attachment of the camera to the frame was found to be without measurable effect on the test values, as can be seen by comparing curves VII and VIII, Fig. 4; when carrying out a test without the camera an equivalent weight was bolted to the camera bracket so as to maintain a constant moment of inertia.

Measurement of the relative amplitudes of vibration of the inertia member and frame showed the ratio to be 154 : 1, as compared with about 10 : 1 before the frame was reconstructed.

The damping capacity of the material of which the test specimen is made is a factor of considerable importance in relation to machine losses. The lower the damping capacity of the specimen, the greater the proportion of the total damping contributed by the machine losses, which are in consequence easier to detect and to measure. It has been shown<sup>1</sup> that some aluminium alloys have low intrinsic damping, especially those of the Duralumin type. At the time this work was begun, there were a number of unused specimens available, both low-carbon steels and aluminium alloys. All the tests up to the stage when the machine frame was reconstructed were carried out using steel specimens, but as the ultimate use of aluminium alloys was visualized, a specimen of R.R. 56 in the fully heat-treated condition was tested in the original unmodified machine in order to obtain data for comparative purposes at a later stage. After completion of the frame reconstruction, it became obvious that the steel specimens available were of no further use for machine-development purposes, and all subsequent work was done with aluminium alloys.

Curve I, Fig. 7, shows the measured damping values obtained when the R.R. 56 specimen was tested in the original machine. The stress range covered by this curve is from 450 to 2600 lb./in.<sup>2</sup>, and it will be seen that in Fig. 4 it would lie to the left and slightly above the low-stress end of the steel-specimen curves.

Reverting to Fig. 7, curve II shows the results obtained when this specimen was tested in the machine after the frame had been reconstructed, and it will be observed that the measured damping has fallen very considerably, a clear indication of the magnitude of the losses inherent in the original design. This test also brought to light an unexpected feature, the low-strain end of the curve showing an apparent sharp increase of damping capacity with decreasing strain. This behaviour could hardly be attributed to a characteristic of the material, as it was entirely contrary to the indications of tests at low stresses carried out by the physical method by other workers. It was assumed, therefore, to be due to a machine loss. Before investigating this phenomenon, however, it appeared desirable to deal with another suspected source of loss.

### *3. Form of Test Specimen.*

The dimensions of the original form of test specimen are shown in Fig. 8, and it will be noted that approximately two-thirds of the length

between the grips consists of square-section shanks, the remainder constituting the cylindrical test length. When a torque is applied to the specimen, therefore, the angular strain is not confined to the cylindrical test length but is divided between the test length and the shanks. Measurements showed that about 22% of the angular strain of the inertia member relative to the frame occurred in the shanks; consequently, the specimen becomes, in effect, two specimens in series, one of square section and the other round. The measured damping must

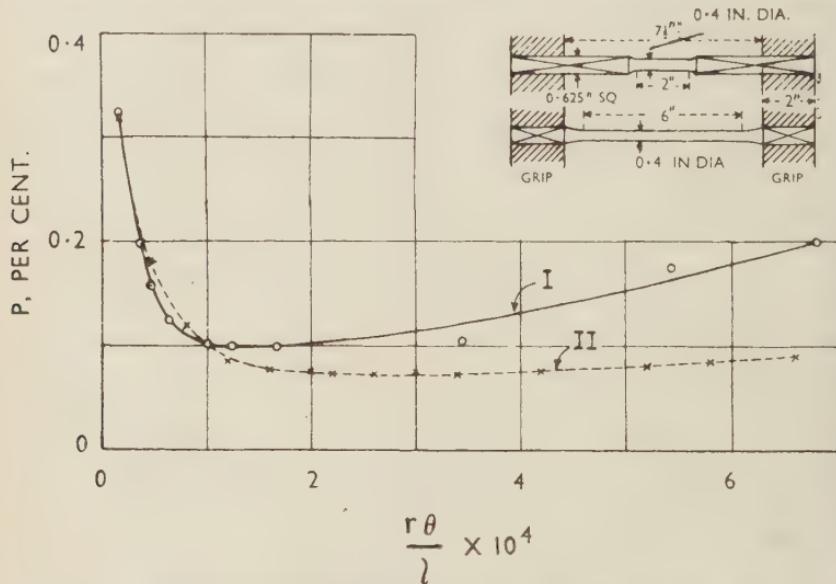


FIG. 8.—Curves Showing Effect of Modifying Form of Specimen R.R. 56.

KEY.

- I. Original specimen. Frequency 420 cycles per minute.
- II. Specimen modified. Frequency 279 cycles per minute.

comprise a summation of (a) that arising within the test length, which is the quantity it is desired to measure, (b) that which occurs in the shanks, and (c) that attributable to the stress-raising effects which may be expected to arise at the junctions of the shanks with the grips and at the change of section between the shanks and the test length.

With regard to (b), it is necessary to bear in mind that, whereas the stress produced in a circular section subject to torsional strain is pure shear and a cross-section remains plane, this is not so for a section of any other form. In the case of a square bar subject to torsion, the stress attains a maximum at the centre of each flat, while at the extreme corners it is zero; further, a cross-section does not remain plane and

the peripheral shape is distorted. As damping capacity is essentially a function of stress, it is clearly most undesirable to interpose between the test length and the machine components a form of section with such a complex stress distribution as arises in the case of shanks of square section. So far as (c) is concerned, the effect of stress raisers is less clear, but as it is likely to be in the direction of an increase in damping capacity, they are best eliminated as far as possible.

In view of the foregoing, it was deemed advisable to modify the original form of test specimen so as to dispense with the projecting part of the square section. This was done by machining away the shanks, the cylindrical test length being increased; the transition to the square section took the form of a gradual radius. The modified form of specimen is illustrated in Fig. 8.

Following this modification, a further test was undertaken, and the result is shown in Fig. 8. It will be seen that at the high-stress end, the measured damping has decreased by a factor of about 50%, the slope of the curve being much reduced; the sharp increase in damping at the low-stress end is, however, virtually unaffected. The decrease in the measured values is not to be attributed wholly to change in form of the specimen; the alteration in the torsional rigidity brought about thereby, resulted in a fall in the frequency of oscillation from 420 to 279 cycles per minute. It may well be (in fact, subsequent work shows it to be most likely) that the decrease owed more to a reduction of the air-friction loss associated with the inertia member than to the change in specimen form.

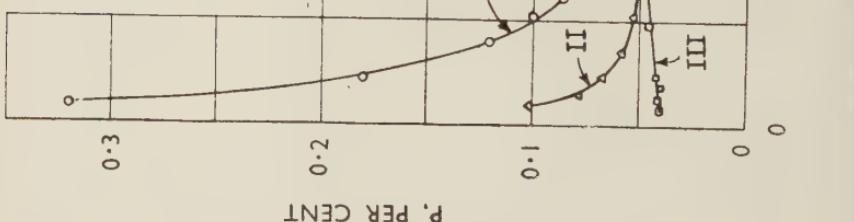
#### 4. *Loss Introduced by Steady-Bearing.*

The cause of the rapid increase in the measured damping with decreasing amplitude, as shown by the curve in Fig. 7, was next investigated. A further test was carried out, and the result is shown in curve I, Fig. 9. The form of this curve suggested that the effect might be due to some energy loss, which is approximately proportional to the amplitude of vibration. Since the strain energy of the system is proportional to the square of the amplitude, such an energy loss would produce a contribution to the measured specific damping capacity inversely proportional to the amplitude of vibration, i.e. of hyperbolic form. Damping forces arising from dry friction are known to be of this form, and so it was suspected that the steady bearing might be responsible for the unusual characteristic shown in Fig. 9.

Arrangements were therefore made to substitute for the existing rather large ball bearing the smallest one commercially obtainable; a subsequent test, the result of which is shown by curve II, Fig. 9,

Fig. 9.—Curves Showing Effect of Removing Steady-Bearing. Tests using rectangular bar as inertia member. R.R. 56 specimen 0.4 in. dia.  $\times$  6 in. long. Frequency 279 cycles per minute.

KEY.  
 I. ○ With original ball bearing.  
 II. △ With minimum size of ball bearing.  
 III. □ Without bearing.



indicated clearly that the bearing was responsible for the increased damping at low stresses, but the effect had been only reduced, and not eliminated, by the fitting of a smaller one. Any form of bearing was, therefore, regarded as undesirable, and the housing was re-designed so as to permit of axial withdrawal of the bearing once it had served its purpose of steadyng the specimen at the start of a test. The form of

curve obtained under these latter conditions is shown by curve III, Fig. 9, and it will be seen that the damping-strain relationship is now virtually linear. In all subsequent tests, the bearing was withdrawn immediately after the inertia member had been released and begun to oscillate.

### 5. *Influence of the Form of the Inertia Member.*

While the improvements to the machine effected up to this stage had resulted in a substantial fall in the measured damping values, these were still much greater than the published results of tests by the physical method on similar materials.

The question of air loss over the inertia member had received some attention previously when the general design of the machine was under consideration, but had been relegated to the category of an error of little consequence as a result of the work of Hatfield, Rotherham, and Harvey.<sup>19</sup> These workers, who carried out an extensive series of damping-capacity measurements with the aid of a machine of the Föppl-Pertz type, investigated the magnitude of the air-friction loss arising from the inertia member, which was in the form of a rectangular bar; the complete machine was enclosed in a container and the pressure therein reduced to 0.01 mm. of mercury, a series of tests being made under these conditions and the results compared with those obtained at atmospheric pressure. Their findings were "that any contributions of air damping to the values of damping capacity recorded may be neglected".

Some preliminary tests, involving an increase in the surface area of the bar without any appreciable change in its moment of inertia, having shown that the air damping of an oscillating rectangular bar was likely to be considerable, it was decided to replace it by a new component.

The more important factors which had to be borne in mind in determining the most suitable form of inertia member were as follows:

(a) Any surface moving in a manner which would result in compression and rarefaction of the air, such as the flat sides of a rectangular bar, and any corners, projections, or changes of shape likely to result in the development of vortices in the surrounding air, must be avoided as far as possible, i.e. a condition of streamline flow is desired.

(b) As air-friction loss is inevitable whatever the shape of the inertia member (unless the machine is operated in a high vacuum, which is impracticable as a normal test condition), then the design of this should be such as to render possible the evaluation of an air-loss correction factor for application to the test results.

The shape which meets the foregoing requirements most closely is a solid of revolution.

The new inertia member is shown in the sketch Fig. 10. It was made from a 0.6%-carbon steel, in the normalized condition. The outer surface was ground to shape, polished, and finally chromium plated. The grip faces were relieved in the manner previously described. Two tapped holes (not shown) were provided in the upper face for the insertion of anchoring bolts, which enabled the member to be securely fastened to the machine frame while tightening the grip bolts. Provision was also made at a suitable point on the periphery for the reception of a screwed arm which was used to operate the dial micrometer for the measurement of the initial angular deflection; this was removed before starting a test. The slit for the optical recording system was situated diametrically opposite to this arm.

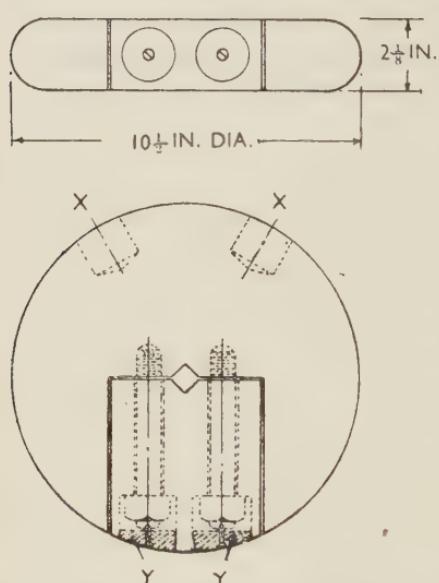


FIG. 10.—Sketch Showing New Inertia Member.

KEY.

X X. Balance holes (cork filled, with ebonite inserts to maintain regular form).

Y Y. Detachable ebonite inserts to maintain regular form.

The fitting of the new inertia member called for an alteration of the release gear. This was transferred to the top cross member of the frame and arranged to engage a small peg situated at the outer limit of the top flat surface of the member.

Advantage was taken of this

opportunity to weld two additional tubular stays between the base ring and the superstructure to ensure still greater rigidity, and also to weld the camera bracket and a balance weight to the frame. A subsequent test, using the original rectangular-bar inertia member, showed these modifications to be without measurable effect.

The machine as it appeared at this final stage of reconstruction, is shown in the photograph, Fig. 11 (Plate XXIV).

Following the substitution of the new inertia member, a series of tests was carried out, using the identical specimen previously employed, and the results are shown by Fig. 12. It will be noted that not only

has the measured damping been reduced by a factor of 80% at the high-amplitude end of the curves, but that the slope of the new damping-strain curve is much reduced and has now become linear.

A subsequent test, using a Duralumin specimen, gave a measured damping capacity of 0.008% at a surface shear stress of the order of 700 lb./in.<sup>2</sup>. Tests carried out on this class of material in the aged condition by Frommer and Murray,<sup>1</sup> using the physical method applied to a "free-free" bar, showed it to have a damping capacity of about 0.0024% at a surface shear stress in the region of 30 lb./in.<sup>2</sup>. At this stage, therefore, the damping as measured by the reconstructed machine

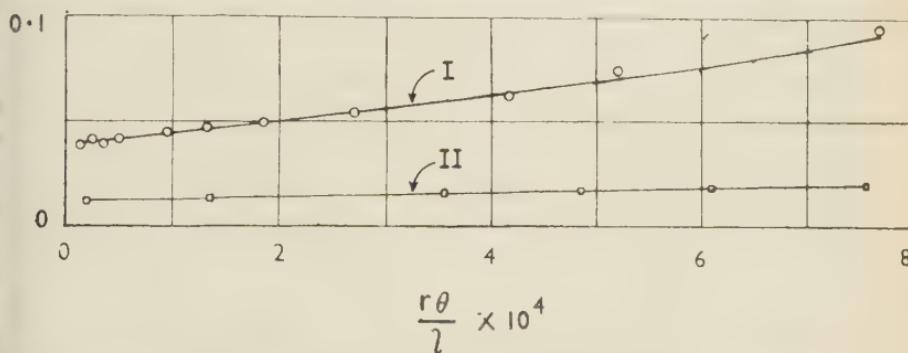


FIG. 12.—Curves Showing Effect of Substituting Wheel for Rectangular Bar as Inertia Member. R.R. 56 specimen 0.4 in. dia.  $\times$  6 in. long. Frequency with bar 279 cycles per minute. Frequency with wheel 318 cycles per minute.

KEY.

- I. With original rectangular bar.
- II. With wheel substituted for bar.

was greater than the physical determination by a factor of about three, whereas prior to reconstruction it was of the order of 500.

#### IV.—THE DESIGN OF THE SMALL MACHINE AND THE MEASUREMENT OF THE AIR-FRICTION LOSS OVER THE OSCILLATING WHEEL.

The next stage was a consideration of the residual energy loss due to air-friction forces over the surface of the oscillating wheel which had replaced the rectangular bar. An experimental determination of this loss was made by two different methods so that the reliability of the measurements could be assessed from a comparison of the two sets of results.

In the first method, the effective area of the oscillating surface was increased by fixing to the periphery of the inertia member a cylindrical ring of a diameter somewhat greater than that of the wheel; the added

moment of inertia was kept to a minimum, and as a result its effect on the frequency of vibration was to produce a decrease of less than 1%. The appearance of the wheel with the ring fitted prompted the designation of experimental determinations by this method as "halo tests".

The second method involved damping measurements at both atmospheric pressures and high vacua, using an apparatus incorporating a small-scale replica of the inertia member used in the modified machine. It was necessary to design a smaller machine specially for this purpose because of the practical difficulty of enclosing the existing machine so that it could be operated satisfactorily at the very low air pressures which theory predicted would be required for the elimination of the air loss.

Both methods lead to the derivation of coefficients which relate the effective air-damping force to the amplitude, and from which the total air damping over the wheel of the large machine may be calculated.

All the test specimens used were machined from one bar of Duralumin in the fully heat-treated condition and of the following composition: copper 4.23, iron 0.47, manganese 0.55, silicon 0.46, magnesium 0.74, nickel 0.06, and titanium 0.03%.

### 1. The Halo Tests.

The halo tests were carried out on the large machine by the usual test procedure and provided the first experimental indication of the existence of a measurable air-friction energy loss over the wheel of the large machine. They also showed the necessity for designing a small machine specifically for the purpose of evaluating this air loss with greater accuracy.

The halo was made from a strip of hard-rolled brass, bent in the form of a cylindrical circular ring giving a radial clearance between the halo and the wheel periphery of  $\frac{1}{2}$  in., and was clamped to the periphery of the wheel at two diametrically opposite points.

In each test, two amplitude-damping characteristics were obtained, one with the halo fixed to the wheel, and the other with the halo resting on the bed of the machine; the specimen remained untouched during the two parts of the test, which were carried out consecutively with the minimum of delay. The difference between the ordinates of the two curves represents the total measured damping capacity arising from air losses over the halo surface and includes any energy dissipation both at the halo clamps and in the material of the halo itself.

### 2. Experimental Results.

The results were found to be reliable only at frequencies of the order of 300 cycles per minute and below; at higher frequencies they were

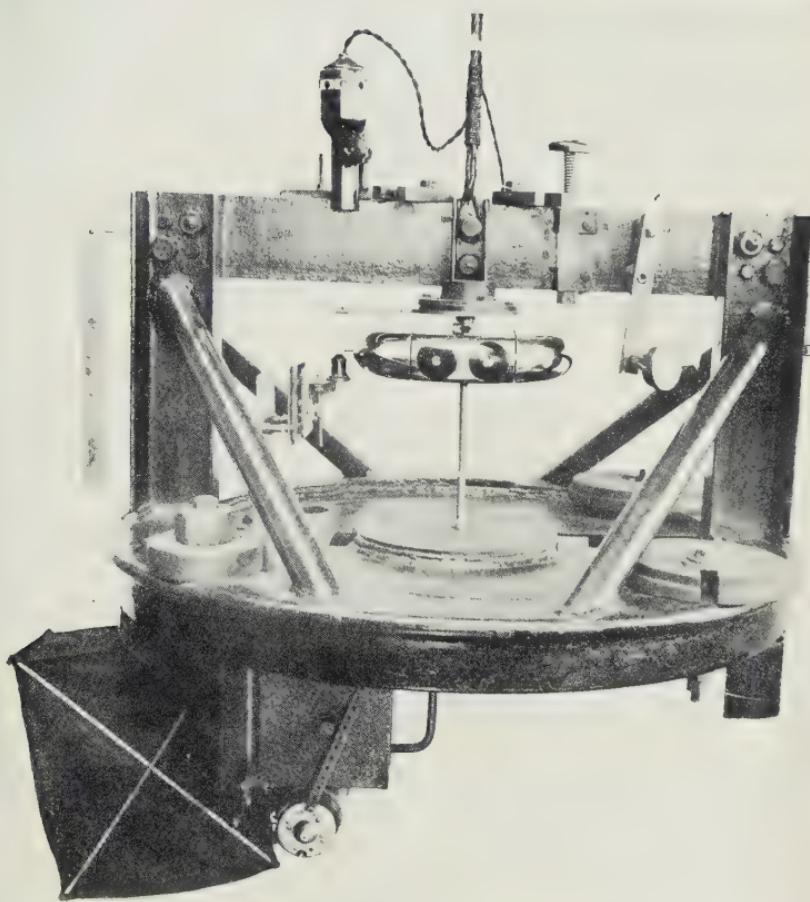


FIG. 11.



FIG. 21.

never reproducible, owing probably to energy dissipation both at the halo clamps and in the material of the halo itself, the effect being enhanced by any slight eccentricity of the halo in relation to the centre of oscillation.

The three points shown in Fig. 17 represent the large-wheel air loss at vanishingly small amplitudes as calculated from three halo tests. The method of calculation is basically similar to that for the pressure tests, as described in Appendix I.

The importance of these halo tests lies in the fact that they have confirmed the order of the air-loss correction factor as determined subsequently by the pressure tests, and have also shown that in the latter a pressure was attained which was sufficiently low to eliminate virtually the whole of the loss due to air-friction forces over the wheel surface.

### 3. *The Pressure Tests.*

As the small machine played a most important part in bridging the gap between measurements by the physical and mechanical methods, in addition to serving its original purpose of determining the air-friction-loss correction factor, its construction and the method of operation will be described in detail.

The small machine was designed primarily in order to assess the air loss over the wheel of the large machine. Since the greater the contribution made by the air loss to the measured damping of the system the more accurately its magnitude can be determined, an attempt was made to design the small machine, in the light of the experience gained with the large one, so that apparatus loss was reduced to a minimum. The result was the production of a machine which not only served its original purpose admirably, but was found to be superior to the large one in almost all respects.

The following description of the constructional details should be read in conjunction with the sketch Fig. 13; a photograph of the machine is shown in Fig. 21 (Plate XXV).

The base of the machine (1) consisted of a high-carbon steel forging of circular form, which was securely bolted to two steel angles (2). The latter were embedded in concrete (3), together with the necessary reinforcing bars, to form a rigid table measuring 5 ft. long  $\times$  2 ft. 6 in. wide  $\times$  9 in. deep, which was supported on three brick pillars resting on a concrete floor; adjusting screws were interposed between the pillars and the table for levelling purposes.

Two steel pillars (4) were screwed into the base and served to support a cross-bar (5), which was sleeved for the reception of the steady-pin

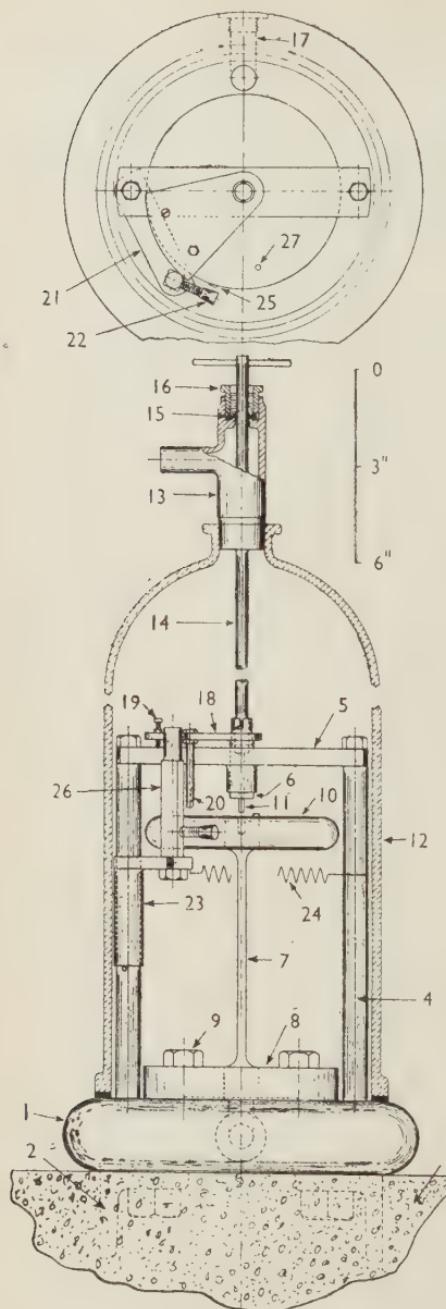


FIG. 13.—Sketch of Small Damping Machine.

guide (6). The bottom shank of the specimen (7) was expanded into the circular grip plate (8), and this was anchored to the base by means of three bolts (9). The central zone of the grip plate was machined away to obviate the possibility of any loss arising from friction between the lower face and the surface of the base due to relative movement in the region of the specimen shank. The top shank of the specimen was expanded into the inertia member (10); this shank was drilled for the reception of the steady pin (11), which could be engaged or withdrawn by axial movement of the guide (6).

The machine was enclosed in a bell-jar (12) which bedded on to a rubber ring to form a pressure-tight joint. The opening in the top of the jar was closed by the gland housing (13), through which passed the actuating rod (14). The gland (15) was originally developed for use with the Berkeley cyclotron,<sup>20</sup> and functioned perfectly. The bell-jar was exhausted through the opening (17). All bolt holes and other cavities were suitably vented to enable entrapped air to escape easily.

It was essential to be able to start and stop the wheel at any time with the jar in position without affecting the pressure inside it. This was ac-

complished by means of a setting and release mechanism which operated as follows :

A cam-plate (18) was attached to the steady-pin guide (6), and as the guide could be rotated or moved axially by means of the actuating rod (14), this motion could be imparted to the plate. The sketch shows the machine in the "running" position; assume the test is completed and that another is to be started. An upward pull on the actuating rod lifts the cam-plate, a conically pointed screw (19) is withdrawn from a hole in the cross-bar and permits the cam-plate to be rotated in an anti-clockwise direction as viewed from the top; the plate is then rotated so as to bring the pointed screw clear of the cross-bar, when downward pressure on the rod results in the cam-plate descending, the steady-pin entering the hole in the end of the specimen at the same time. This axial movement is limited by an adjustable stop (not shown) so that the end of the setting pin (20) is just clear of the surface of the wheel.

The trigger gear consists of an arm (21) carrying an adjustable catch (22); the arm is secured to a sleeve (23) rotating about one of the columns and is subject to a pull by means of the spring (24) tending to bring the catch into contact with the trigger peg (25). Under running conditions, the catch is held clear of the pin by the edge of the cam-plate bearing on the top end of the pillar (26). Further rotation of the cam-plate in an anti-clockwise direction allows the pillar (26) to ride down the cam-face until the catch (22) makes contact with the trigger peg (25); on continuing the rotation, the setting pin (20) ultimately engages the setting peg (27), which enables a torque to be applied to the wheel by means of the actuating rod. When the angular deflection corresponding to the setting of the catch (22) is attained, the catch engages the peg (25) and thus retains the wheel in the deflected position.

To start the wheel oscillating, the movement of the cam-plate is carried out in reverse; clock-wise rotation results in the cam-face pushing the pillar (26) outwards, thus disengaging the catch and releasing the wheel. The cam-plate is then lifted by means of the actuating rod, thus withdrawing the steady-pin from the hole in the end of the specimen; further slight rotation serves to bring it into the "parking" position.

The amplitude of vibration of the inertia member was measured optically, as indicated diagrammatically in the sketch Fig. 14, which also shows the general arrangement of the apparatus. The image of an illuminated slit was reflected on to a translucent scale by a small face-aluminized mirror fitted into a recess in the periphery of the inertia member.

The manner of gripping the specimen shanks was the subject of

much consideration. Tests on the large machine had afforded ample grounds for suspecting that it was inadvisable to use square shanks. It was decided finally to employ a specimen with cylindrical shanks of slightly taper form, expanded into the inertia member and grip plate. The holes in the inertia member and grip plate were machined to a taper of 1 in 50 on the diameter, the latter being  $1\frac{1}{8}$  in.; the specimen shanks were accurately ground to the same taper. Prior to final assembly, each shank was immersed in liquid oxygen and was then

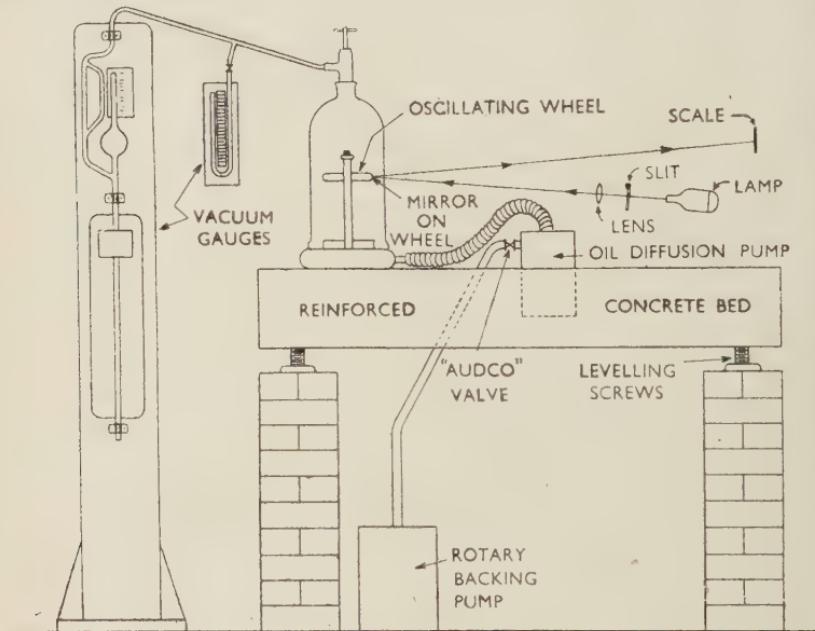


FIG. 14.—Sketch Showing General Arrangement of Apparatus and Optical Method of Measuring Amplitude of Vibration of Inertia Member.

rapidly inserted in the hole. Experience showed that a shank machined so that it projected  $\frac{3}{16}$  in. above the end of the hole would, after cooling, enter the hole the correct distance, bringing the shoulder flush with the surface of the wheel or grip plate.

Expansion of the shanks was selected in preference to shrinkage of the inertia member and grip plate for two reasons. Firstly the temperature required to obtain sufficient shrinkage to ensure adequate gripping would be relatively high and likely to affect the damping properties of the specimen, and secondly it would be undesirable to subject the inertia member to a series of heatings on account of possible changes in the surface condition. The method used proved most

successful and is considered to be one of the factors responsible for the extremely low measured damping values obtained with this machine. The one serious disadvantage is that destruction of the specimen is necessary to effect removal, as the centres of the shanks must be bored out to relieve the radial compression before they can readily be dislodged. A test carried out on the grip plate showed that an axial load of about 8000 lb. was required to dislodge a shank which had not been bored out.

#### 4. *Experimental Procedure.*

Tests were carried out at five different frequencies, ranging between 150 and 1170 cycles per minute, obtained by using specimens, of similar form but different test-length diameter, machined from the same bar of Duralumin. It was considered impracticable to reduce the diameter of a specimen in stages after it had been expanded into the wheel and grip plate of the machine, and since this method of gripping the specimen prevented it being removed without damage it was necessary to use a new specimen for each frequency. Since only differences of damping capacity were required in each test, no errors were introduced by any slight variation of damping capacity from one specimen to another.

At each frequency two characteristics were obtained connecting the measured damping with the amplitude,  $\theta$ , one at atmospheric pressure and the other at very low air pressure; the air damping was obtained as a function of  $\theta$  from the difference between the ordinates of these curves.

A series of intervals of equal amplitude-fall were timed with the aid of two stop-watches; at the end of each interval one watch was stopped and the other started simultaneously; thus the final amplitude of the first interval was the initial value for the second and so on.

The frequency of vibration of each specimen was obtained photographically by recording on a moving strip of sensitized paper the number of cycles during a definite period of exposure (usually 20 sec.).

The first test to be carried out was to measure the variation of damping capacity with air pressure, by timing the fall of amplitude between two fixed limits, as the pressure was decreased in stages to a figure of the order of  $10^{-3}$  mm. of mercury. The results of tests on four of the specimens, covering a pressure range from about 760 mm. of mercury down to about  $10^{-3}$  mm., are shown in Fig. 15. The curves become practically horizontal at low pressure, and this was taken as an indication that at about  $10^{-3}$  mm. the major portion of the air loss is eliminated.

KEY.

Curve.	Specimen No.	Dia., in.	Frequency, cycles per minute.	Remarks.
I	$C_1$	0.312	738	Mean damping capacity over the range $\theta = 0.054$ to $\theta = 0.045$ radians.
II	$C_2$	0.244	455	Tests carried out by mechanical method in the small machine.
III	$C_3$	0.199	299	
IV	$C_4$	0.140	149	
V	$C_5$	0.312	48,240	Test by physical method prior to mechanical tests shown by Curve II.
Point ●	$C_2$	0.244	30,780	

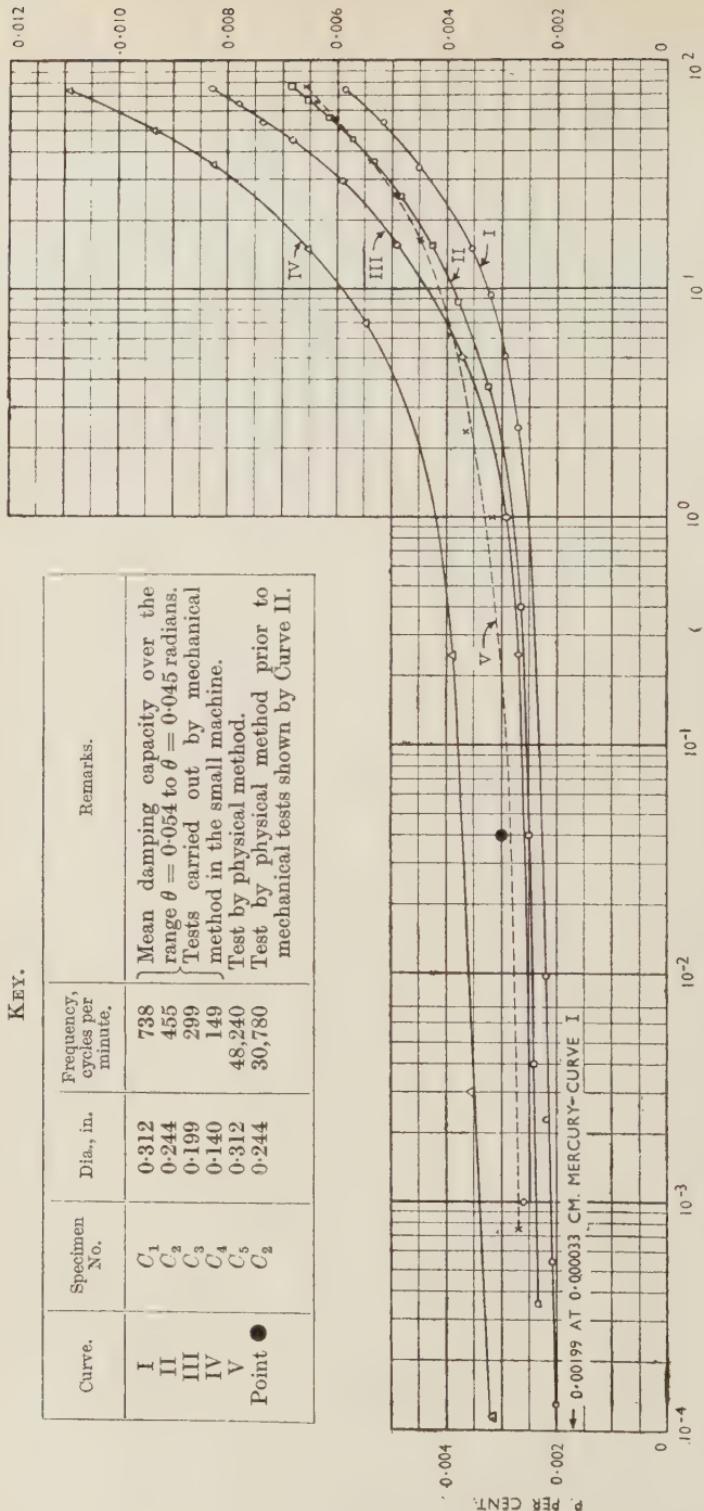


FIG. 15.—Curves Showing Variation of Measured Damping Capacity with Air Pressure. Duralumin specimens, all machined from same bar, test length 6 in.

After this test had been carried out on any one specimen, two amplitude-damping characteristics were obtained, one at atmospheric pressure and the other at about  $10^{-3}$  mm. The results for all the five specimens tested are illustrated in Fig. 16.

It will be appreciated that in all cases the characteristics connecting the air damping with  $\theta$  are linear, and that the contribution to the measured specific damping capacity by air-friction forces over the wheel may be represented by an expression of the form  $A + B\theta$ , where  $A$  and  $B$  are constants at any frequency.

### 5. Some Further Experiments.

Some experiments were carried out to determine the effect of certain possible sources of error, of which the more important will be described briefly.

The setting peg and other unavoidable excrescences on the wheel of the large machine were not reproduced on the smaller replica, since it was thought desirable to separate the contributions made by air friction over the wheel surface and the effect of the excrescences. The most serious "excrescence effect" seemed likely to arise from a projection such as the setting peg in the inertia member of the large machine. With a view to ascertaining whether this loss was of appreciable magnitude, two light-alloy pegs, of similar size and form to the one on the large machine, were fixed in small holes drilled in the wheel at the outer limit of the flat top surface in diametrically opposite positions. Two pegs were used, firstly to avoid any tendency to throw the wheel out of balance, and secondly to double the magnitude of the effect it was desired to measure. They produced no detectable change in the measured damping values in any test in which they were used, and it was concluded from this that small excrescences produce air-friction losses which are insignificant when compared to the total air loss over the wheel surface.

In addition to the setting peg, other irregularities existed in the case of the large wheel in the form of slots connected with the clamping insert, holes for the reception of anchor bolts, &c. These cavities might be expected to exercise a two-fold effect on the air-friction loss, firstly by movement of the air within the cavities, and secondly due to interruption of streamline air flow over the surface. All these cavities were tightly packed with cotton wool and the surface irregularities substantially reduced by covering the openings with very thin adhesive "Cellophane" tape. No difference in the measured damping capacity could be detected as a result of these measures, from which it would appear that small cavities are as innocuous as small excrescences.

Added evidence in favour of the statement that all the air loss is eliminated at air pressures of the order of  $10^{-3}$  mm. of mercury was obtained by tests in a gas with much lower viscosity, namely hydrogen. A test was carried out in dry hydrogen at atmospheric pressure, the jar

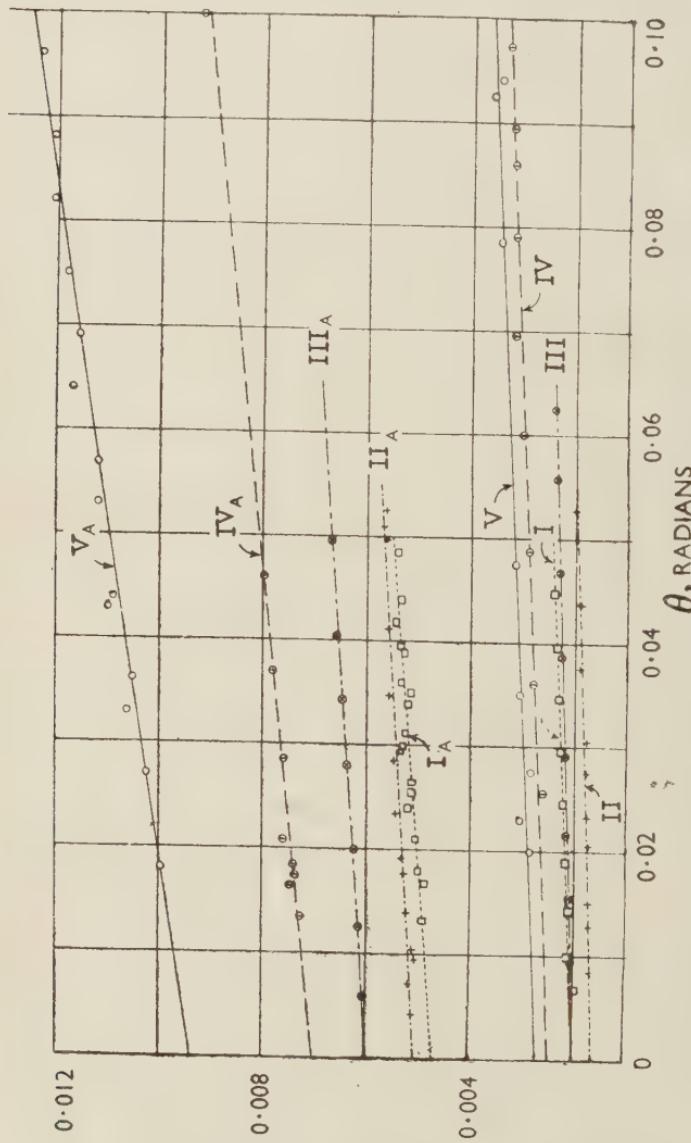


Fig. 16.—Curves Showing Results of Pressure Tests. Duralumin specimens, test length 6 in.

For Key, see p. 401.

being filled and exhausted three times to ensure that as little air as possible remained in the apparatus.

The substitution of hydrogen for air resulted in a marked decrease in the measured damping values at atmospheric pressure; in each case the damping tended to the same value at low pressures.

In order to arrive at some indication of the reproducibility of the pressure-test results, a new specimen,  $C_8$ , was prepared with dimensions identical to  $C_1$  and the air loss re-determined. The results of the tests on the two specimens were as follows :

$$C_8 : Pa = 0.0034 + 0.00580 \text{ at 747 cycles per minute.}$$

$$C_1 : Pa = 0.0034 + 0.00870 \text{ at 738 cycles per minute.}$$

#### 6. Air Loss Over Wheel of Large Machine.

The contribution to the measured specific damping capacity made by air-friction forces over the wheel of the large machine was calculated from the results of the pressure tests on the small machine. The theory is outlined in Appendix I. In Fig. 17, the large-wheel air damping is shown as a function of the frequency of vibration at two angular amplitudes, namely  $\theta = 0$  and  $\theta = 0.02$  radians. By virtue of the linear law of variation with amplitude at a constant frequency, Fig. 17 thus determines the amplitude characteristic completely at any frequency within the range of the experiments.

It must be emphasized that Fig. 17 applies only to aluminium alloy specimens, or, more strictly, to specimens with a test length 6 in. long, whose modulus of rigidity is  $3.59 \times 10^6$  lb./in.<sup>2</sup>

KEY TO FIG. 16.

Curve.	Specimen No.	Dia., in.	Fre-quency, cycles per minute.	Pressure.
I <sub>A</sub> I	$C_7$	0.4	1170	{ Atmospheric 0.002 mm. mercury } $Pa = 0.00273 + 0.006 \theta$
II <sub>A</sub> II	$C_1$	0.312	729	{ Atmospheric 0.0003 mm. mercury } $Pa = 0.0034_2 + 0.006 \theta$
III <sub>A</sub> III	$C_2$	0.244	455	{ Atmospheric 0.005 mm. mercury } $Pa = 0.0040 + 0.0072 \theta$
IV <sub>A</sub> IV	$C_3$	0.199	299	{ Atmospheric 0.003 mm. mercury } $Pa = 0.00456 + 0.013 \theta$
V <sub>A</sub> V	$C_4$	0.140	149	{ Atmospheric 0.0013 mm. mercury } $Pa = 0.0067_6 + 0.021 \theta$

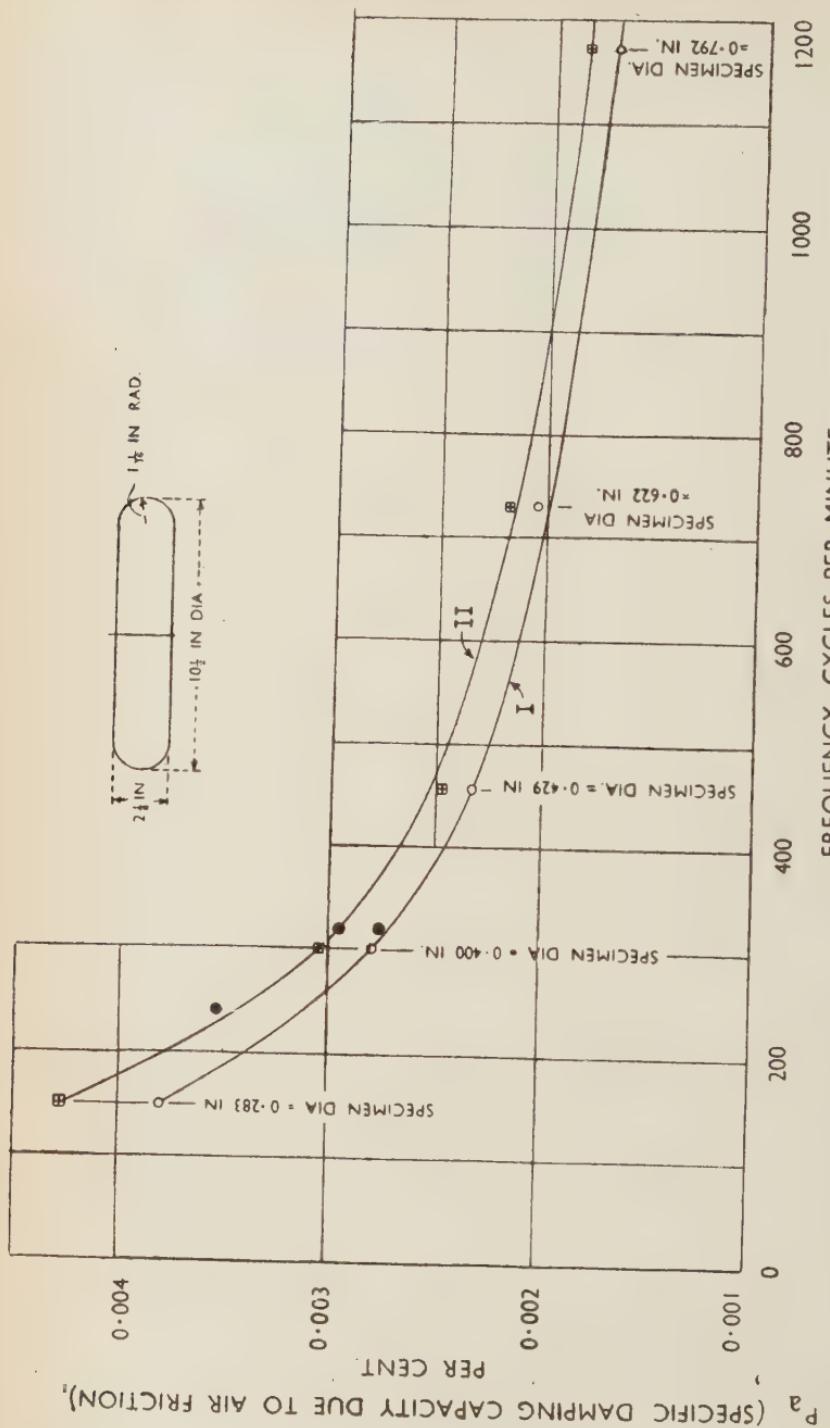


FIG. 17.—Curves Showing Calculated Variation of Air-Friction Damping Over a Wheel of the Form and Dimensions Shown Above, with a Polished Chromium-Plated Surface. Applicable to any specimen material with a modulus of rigidity of  $3.55 \times 10^6$  lb./in.<sup>2</sup>

KEY.

## V.—TESTS BY A PHYSICAL METHOD.

Specimens  $C_1$  and  $C_2$ , used in connection with the air-friction-loss determinations, were both tested by a physical method before they were expanded into the wheel and grip plate of the small machine.

The apparatus used for these tests owed much to the work of Hanstock and Murray.<sup>4</sup> The only important differences between the two forms of apparatus were, firstly the feed-back arrangement developed by Hanstock and Murray was not used for the excitation of vibration, and secondly provision was made for carrying out tests at low air pressures in order to eliminate the air loss.

The specimen was suspended by a 0.005-in.-dia. copper-beryllium wire, soldered into brass terminal pieces, one of which was threaded for screwing into the end of the specimen. It was excited into torsional vibration electromagnetically by feeding an exciter from a variable-frequency valve oscillator. The exciter worked on the well known principle of the interaction between eddy currents generated in the end of the specimen and a polarizing field. The decay of amplitude after the exciting force had been removed was timed from the fall in the amplified output voltage from a detector working on the same principle as the exciter. The whole of the apparatus was enclosed in a bell-jar so that tests could be conducted at low pressures.

The logarithmic decrement was measured from the time taken for the output voltage to fall to half of its initial value after the exciting force had been removed. Two successive measurements were taken, the gain of the amplifier being doubled after the first reading.

The results obtained on  $C_1$  were :

Pressure.	Frequency.	$P_1$ .	$P_2$ (after gain of amplifier doubled).
0.0013 mm.	$\left\{ \begin{array}{l} 805 \text{ c./s.} \\ (48,300 \text{ cycles} \end{array} \right\}$ per minute)	0.0039%	0.0038%
atmospheric		0.0077%	0.0075%

The measured damping is thus approximately halved when the pressure is reduced to  $10^{-3}$  mm. of mercury.

The measurements include some damping introduced by eddy currents produced in the end of the specimen due to the polarizing field. In the case of the exciter, this loss was eliminated by using an electromagnet which was switched off while measurements were taken. The detector loss could not be eliminated in this way and was thus an unavoidable contribution to the measured damping; it was kept to a minimum by supplying the polarizing field from a weak permanent magnet, and the magnitude of the residual error introduced was assessed in the following manner :

A test was carried out on a specimen with one end expanded into the grip plate of the small machine, which enabled the amplitude to be measured optically; the damping was measured firstly with the detector in position, secondly with only the polarized exciter present, and thirdly with both removed. These results enabled the exciter and detector losses to be assessed at this frequency. It was assumed that the ratio of the losses would be approximately the same at any frequency for the same material and similar inertia dimensions. The detector loss could therefore be ascertained in any test by measuring the exciter loss and deriving the former by simple proportion.

The detector loss obtained in this manner at 805 cycles per second was about 0.0007%, whence the corrected values for the specific damping capacity of specimen  $C_1$  measured by this method are: 0.0032% and 0.0031% at a stress of 2000 and 900 lb./in.<sup>2</sup>, respectively. When this specimen was tested in a vacuum in the small mechanical machine used for the pressure tests, a measured damping of 0.0017% was obtained at a stress of the same order, the frequency being 738 cycles per minute.

Specimen  $C_2$  was tested similarly; at a frequency of 513 cycles per second it had a measured specific damping capacity of 0.0043%, and an estimated detector damping of 0.0009%, i.e. a value of 0.0034% for the intrinsic damping of the material. At a similar stress and a frequency of 455 cycles per minute, this specimen had a damping of 0.0020% when measured in the small mechanical machine.

Two specimens of R.R. 88, kindly supplied by Dr. R. F. Hanstock, of Messrs. High Duty Alloys, Limited, after they had been tested by him, gave results virtually identical with his when tested with this apparatus at atmospheric pressure.

#### VI.—FURTHER EXPERIMENTS ON GRIP LOSS.

At this stage in the investigation, the measured damping capacity of Duralumin at low stresses was of the order of 0.006% when tested in the large machine under normal conditions, and after applying the appropriate air-loss correction. When tested in the small machine, at a reduced air pressure sufficient to eliminate the air-friction loss, a specimen cut from the same bar showed a measured damping capacity of 0.002%. While a residual machine loss of 0.004% may appear insignificant, it is nevertheless about twice the intrinsic damping capacity of the Duralumin used. It was suspected that it might be due to losses arising from the gripping of the specimen shanks, which had not then been investigated fully.

In the case of specimens with square shanks, energy losses at the grips may arise from :

- (a) Relative movement at the specimen-grip interfaces.
- (b) Damping within the material of which the grips are made.
- (c) The complex stress system within the shank, arising from the combination of torsion and radial pressure due to gripping.

In the case of (a), varying the tightness of the grip bolts will affect the interfacial pressure; a difficulty arose, however, in that the weight of the inertia member is carried by the specimen, therefore the grip bolts could not be left loose to the desired extent. Use was therefore made of a specimen of R.R. 88, which was machined in the form of a test length 0.3 in. dia.  $\times$  6 in. long, with one end in the form of a shank 0.625 in. square. The other end was in the form of an integral inertia, 1.2 in. dia.  $\times$  2 in. long, in order to obviate the need for gripping the specimen at both ends; losses due to gripping were thus confined to one end only. The specimen was excited electromagnetically in the manner previously described and the decay of the oscillations detected optically.

The result of varying the tightness of the grip bolts was a change in the measured damping. With the bolts hand-tight, an audible rattle occurred and the measured damping was approximately doubled; as the bolts were tightened progressively, the measured values decreased and attained the normal value when the bolts were tightened to the usual extent, but excessive tightening produced no further decrease. It was found that insufficiently tightened bolts affected the change of the measured damping with strain, the damping increasing more rapidly with increased strain; the values at vanishing amplitude were also greater, but the characteristics remained linear throughout.

The effect of interposing thin strips of soft steel (0.032 in. thick) between the grip faces and the specimen shanks, thus doubling the number of interfaces, was found to increase the measured damping by about 0.0005%, the slope of the curve being unaffected; the use of lead and also paper strips (both 0.007 in. thick) gave similar results of slightly greater magnitude. It is considered probable that the damping within the strips themselves is largely if not wholly responsible for this slight increase.

The influence of the material of the grips was next investigated. The integral bottom grip of the large machine was made of a 0.6%-carbon steel in the normalized condition, a material of high damping capacity compared with Duralumin. If the grip material introduced appreciable damping, then the substitution of a grip constructed from

Duralumin should reveal the magnitude of the effect. A special massive Duralumin grip was therefore made; the dimensions and form of the grip faces were identical with those of the steel grip, and it was secured

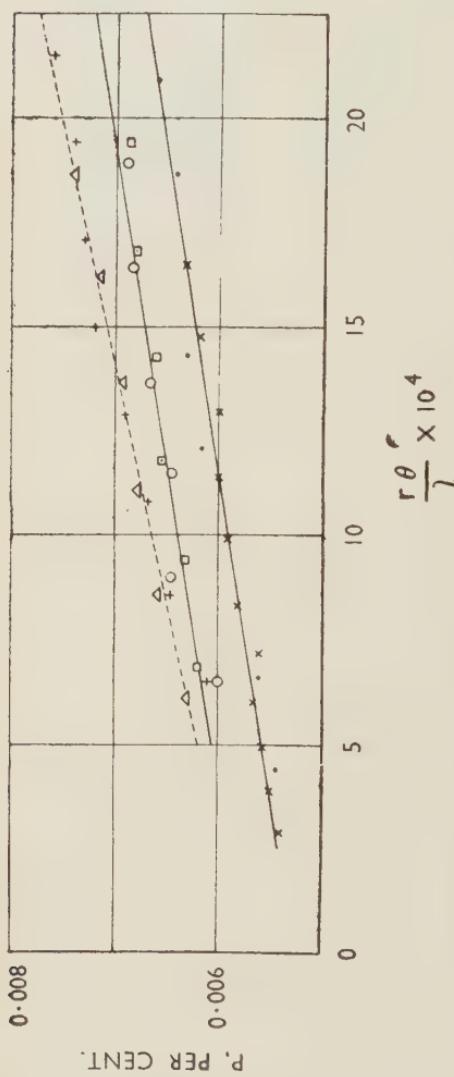


Fig. 18.—Grip-Loss Tests. Duralumin specimens 0.312 in. dia.  $\times$  6 in. test length.

Cylindrical taper top shank of specimen expanded into small-machine inertia member, bottom shank standard 0.625 in. square section.

- Specimen held in steel grips, square shank not protruding above grip. Frequency 727 cycles per minute.
- + Specimen held in steel grips, square shank protruding 1 in. above grip. Frequency 724 cycles per minute.
- Specimen held in Dural grips, square shank not protruding above grip. Frequency 727 cycles per minute.
- △ Specimen held in Dural grips, protruding 1 in. above grip. Frequency 427 cycles per minute. Both shanks of specimen of cylindrical taper form expanded into small-machine inertia member and grip plate.
- × Tested in small machine at atmospheric pressure. Frequency 743 cycles per minute.
- Tested in large machine; grip plate bolted to bottom machine grip. Frequency 747 cycles per minute.

member belonging to the small machine. The results of this series of tests are shown in Fig. 18. The specimen was first tested with the end of the square shank flush with the top of the steel grip; the Duralumin grip was then bolted into place, the specimen clamped in it, and another test carried out. No difference was observed greater than the experimental error, from which it may be concluded that, within the limits of the strain energy used in these tests, the energy loss in the material of the grip is insignificant. This is in agreement with an approximate calculation which indicated that, even if the whole of the strain energy in the grip plate was lost during each cycle, the additional damping introduced would be of the order of 0.000001% for a 0.4-in.-dia.  $\times$  6-in. Duralumin specimen.

It was convenient at this stage to carry out some tests on the effect produced by gripping a specimen shank so that the square part protruded above the surface of the grip. The specimen described in the previous paragraph was used, and its dimensions imposed a limit of 1 in. on the extent of the protrusion. Tests were carried out in both the steel and Duralumin grips, and the results are shown in Fig. 18. It will be seen that the exposed shank raises the measured damping slightly, the increase being a function of the amount of strain, from which it is apparent that the damping capacity of a square specimen in torsional vibration is greater than in one of circular section. This is evidence in favour of the hypothesis that the residual grip loss arises from the enhanced damping associated with the complex stress distribution arising in a square bar in torsion, especially when the complexity is increased by radial pressure.

The next test in this series involved the use of a Duralumin specimen of 0.312 in. dia. with taper shanks expanded into the inertia member and grip plate of the small machine. This assembly was tested in the large machine by securely bolting the grip plate to the integral machine grip; it was afterwards removed and tested in the small machine at atmospheric pressure. The test data are shown in Fig. 18, and it will be noted that there is no variation in the measured damping obtained with either machine outside the range of experimental error; there is, however, a decrease of about 0.0005% as compared with the results obtained in the case of a similar specimen with a square shank held in the large machine grip. If the two specimens have almost identical damping characteristics (they were machined from the same bar), it follows that the presence of a square shank gripped in the large machine introduces a loss of the order of 0.0005%, and as there are two such shanks when using the large inertia member, the total "gripping loss" in the large machine was tentatively assessed to be 0.001% for a

specimen of similar diameter at the particular strain energy at which these tests were carried out.

The exact manner in which this loss arises is not clear; it has been found that the material of which the grip is made is not responsible, and that once the grip bolts are tightened to a certain degree further tightening does not reduce the measured damping, which suggested that interfacial movement was not a serious factor. The complex nature of this grip-loss is well illustrated by some experiments which were designed to ascertain if variations in ambient temperature affected the measured damping capacity. A specimen was tested in the large machine under standard conditions. The test length was then enclosed by a cardboard cylinder, and a second test commenced; after two readings had been obtained, a stream of air heated to approximately 80° C. was passed through the cylinder for the purpose of warming the specimen test length, the air supply being discontinued prior to taking a reading. The result of several such tests on different materials was surprising; the first test readings under standard conditions conformed to the usual values, and the damping-strain relationship was linear. This was also the case for the readings obtained in the second test before the admission of hot air, but those obtained subsequent to heating showed a marked increase in the measured damping; in the case of R.R. 88 aluminium alloy, the increase was of the order of 50%, while Duralumin and R.R. 56 showed a rise of about 20%. By alternately heating and cooling the specimen, the damping values obtained could be made to see-saw up and down at will. When the specimen had returned to room temperature, the test results reverted to the normal values.

The experiments were repeated, firstly on the small machine working under standard conditions, and secondly with the small-machine inertia member, specimen, and grip plate affixed to the large machine. The increase in measured damping following heating of the specimen test length, in the manner previously described, was in both cases either not detectable or very small. The essential difference between the two groups of tests was that in one the specimen shanks were square and held in bolted grips (large machine), while in the other the shanks were cylindrical and were expanded into the machine components. The heat absorbed by a specimen test length would be conducted to the shanks, which would expand in consequence, to an extent dependent upon the rate of heat conduction to the grips, and thus increase the interfacial pressure at the grip-shank surfaces. In the case of a specimen with square shanks, the effect of this would be to decrease any relative movement at the surfaces in contact, so that any energy losses resulting from such movement would be reduced, i.e. the measured damping

would be less. That it was in fact greater suggests that, with the modified form of grip surfaces concerned, the losses at the grip-shank interfaces are insignificant if the grip bolts are properly tightened. It will be noted that expansion of the specimen relative to the grip increases the compressive stress imposed on the shank, and it seems likely that the extremely complex stress system which exists within a square section is largely responsible for the grip-loss which arises in a shank of this form.

This "temperature-damping" relationship has an important practical implication. A number of workers<sup>8, 12, 15</sup> using Föppl-Pertz-type machines have surrounded the specimen with a furnace and carried out tests at elevated temperatures. It may well be that the damping-temperature characteristics thus obtained are not free from serious error due to changes in damping induced by variations of temperature in the region of the grips.

The residual large-machine loss of about 0.004% is thus reduced to 0.003% if the tentatively established grip loss is deducted. In view of the complete agreement when the small-machine assembly was tested both in the small and large machines, it would appear that in this case there is no loss associated with the large-machine frame. Under standard test conditions, however, the position is different; the ratios of the polar moments of inertia of the oscillating masses differ considerably, with the result that, when using the small-machine inertia member in the large machine, the amplitude of oscillation of the frame is much less than is the case when the standard inertia member is used. Oscillation of the frame must result in energy loss due to air friction over it, while other losses may arise within the multi-strand suspension cable, and possibly as a result of slight relative movement of accessories clamped to the frame. Careful consideration was given to the experimental procedure which appeared necessary to determine the individual contribution made by these factors to the residual machine loss, and it was concluded that the results likely to be obtained would not be commensurate with the amount of work involved. Having regard to the fact that the small machine was free from these sources of error and superior to the large one in nearly all respects, it was decided to terminate development work on the large machine at this stage.

## VII.—DISCUSSION.

The salient fact arising from this investigation is that, in the case of materials of relatively low damping capacity, the measured damping values obtained with a machine based on the Föppl-Pertz design are

no indication of the true damping capacity of the material under test, as the machine losses completely mask the contribution made by the test specimen itself. In the case of the particular machine used in this work, it has been found that the measured values may be of the order of 500 or more times the true damping capacity of the material.

The most serious energy losses in the original machine arose from lack of frame rigidity, the high air-friction loss inseparable from a bar type of inertia member, and inadequate gripping of the specimen, while the steady-bearing produced serious distortion of the damping characteristic. The air-friction loss associated with a "swing bar" inertia member is prohibitively high, and the only satisfactory solution appears to be to design it in the form of a solid of revolution, of smooth surface finish and free from avoidable irregularities of form. The damping introduced by a ball type of steady-bearing increases rapidly below a certain strain energy, and in consequence the use of such a bearing is most undesirable. By suitable modification to the faces of the grips, the loss associated with gripping a specimen with square shanks can be reduced to a low value, but shanks of taper cylindrical form, expanded into the machine components, are much to be preferred.

With regard to the determination of the air-loss correction factor, it has been established that the results obtained for the air loss over the inertia member of the large machine by two different methods (the halo and pressure tests) are in good agreement within the range where the former are reproducible and therefore, presumably, reliable.

The agreement between the halo and pressure tests, coupled with the form of the pressure-damping characteristics in air and hydrogen, indicate that the air loss can be considered virtually absent at pressures of the order of  $10^{-3}$  mm. of mercury. The halo tests are susceptible to more inherent errors and are the less accurate, since the fraction of the damping contributed by air loss over the halo is much less than the fraction arising from the air damping over the surface of the inertia member used in the small machine. Thus, the pressure tests were used for the accurate assessment of the air loss, and the halo tests were considered to be of a merely confirmatory nature.

The small machine, constructed primarily for carrying out the pressure tests, gave at low pressures a value of the order of 0.002% for the specific damping capacity of fully heat-treated Duralumin. There is good reason, discussed later, to believe that this value represents a fairly close approach to the order of the intrinsic damping of Duralumin in this condition, consequently the energy loss due to air-friction forces over the inertia member of the large machine, within the normal operating frequency range, may exceed 1.5 times that due to the internal

friction in the specimen. This factor will be even greater for a machine with an inertia member of smaller moment of inertia or oscillating at a lower frequency; for example, in the case of the small machine the factor becomes 3.5 at 150 cycles per minute. The air loss over the inertia member, when expressed as a specific damping capacity, has been shown to increase linearly with the amplitude of vibration, and both the magnitude of the loss and the variation with amplitude are greatest at the lower frequencies within the range 150 to 1170 cycles per minute. This linear variation of air loss does not apply in the case of a rectangular-bar inertia member, where the loss increases more rapidly with increasing amplitude.

An unexpected feature of the results is the form of the variation of air damping with pressure (Fig. 15). If it is assumed that the energy loss arises from a viscosity effect, then both the Kinetic Theory and its experimental verification by Maxwell<sup>21</sup> indicate that there will be no variation of viscosity, and hence little change in the air damping, at pressures above those of the order of 1 cm. of mercury, where, as the work of Millikan<sup>22</sup> and others has shown, slip between the oscillating surface, and the layer of air in contact with it becomes appreciable.

The air-friction-loss data relate only to an oscillating member of a particular form with a polished, chromium-plated surface; the effects of variations of form and surface finish have not been investigated.

The results of the tests carried out at low air pressure by the physical method on two of the specimens gave values for the specific damping capacity greater than those obtained with the same specimens in the small mechanical machine at pressures of the order of  $10^{-3}$  mm. of mercury. The tests also show that a serious air loss occurs over the surface of specimens of this form, which may be of the same order as the damping of the material itself in the lower frequency range of the physical method (about 1000 cycles per second) and confirms the statement by Hanstock and Murray<sup>4</sup> concerning the air losses over their specimens.

Experiments failed to detect any residual losses in the physical apparatus which would account for the discrepancy. A decrease in the length of the suspension wire, and the fitting of two suspensions, one above and the other below the specimen, failed to produce a change in the measured values; it would appear, therefore, that the suspension loss is negligible.

A comparison of the measured damping values for a particular material, tested in both the large and small machines, shows that the latter invariably gave the lower values. This is ascribed largely to the improved form and method of gripping of the specimen shanks as

compared with the large machine, and the rigid attachment of the machine to a concrete bed, thus eliminating energy losses arising from air friction over the frame and via the suspension cable. Apart from the decrease in the energy losses, anchoring the machine greatly facilitates manipulation and enables visual reading of an image on a scale to be substituted for photographic recording, thus effecting a considerable saving in time, since the processing and subsequent measurement of the trace, inseparable from photographic recording, is eliminated. Experience has also shown the visual method to be slightly more accurate than the photographic.

It is believed that the measured damping capacity obtained with the small machine is a close approximation to the true value. This conclusion is based on the following experimental evidence :

(a) The measured damping capacity of specimen  $C_1$ , tested in the small machine at low air pressure, was 0.0016% at a stress of 900 lb./in.<sup>2</sup>. When this identical specimen was tested by the physical method, also at low air pressure, the measured value obtained was 0.0031% at the same stress. The corresponding values for specimen  $C_2$  were 0.0021 and 0.0033%.

(b) Tests carried out by Frommer and Murray<sup>1</sup> on fully heat-treated Duralumin gave a damping capacity of the order of 0.0024% at very low stress.

In the case of their apparatus it is stated that the total error in the measured logarithmic decrement is less than 6%, while the lowest damping capacity recorded was 0.0012% for Duralumin in the extruded condition. It is clear, therefore, that the value of 0.0024% obtained by them for fully heat-treated Duralumin is not simply a minimum dependent on the magnitude of the total apparatus loss but represents a close approach to the intrinsic damping capacity of the material in that condition.

(c) The result obtained by Hanstock and Murray<sup>4</sup> for Duralumin was 0.0028% after correction for external losses. The physical method developed by the authors was essentially similar to that originated by Hanstock and Murray, and it will be seen that the values obtained by the two pieces of apparatus are in close agreement.

The five specimens used in the pressure tests showed, at low pressures, a variation in measured damping capacity over the range 0.0016 to 0.0026%. This may be due, for example, to some axial or radial changes in the properties of the material through the bar from which the specimens were machined, to some effect resulting from machining, or to a change in some small residual apparatus loss.

The experimental evidence is insufficient to indicate which of these is responsible.

While the agreement between the physical and mechanical determinations supports the belief that the damping capacity of Duralumin is not seriously frequency-sensitive, it has not been established that it is completely independent of frequency. It is possible, for instance, that the range of variation of the measured damping of the five pressure-test specimens is to be ascribed, wholly or in part, to a variation of the damping with test frequency. Clearly, the matter is one of considerable importance, and further work is in hand with the object of obtaining some conclusive evidence.

In conclusion, it is perhaps desirable to emphasize that the work described has been carried out using test specimens of very low damping capacity. It has been shown that the published results of damping-capacity measurements on such low-damping materials are seriously in error when using a machine based on the Föppl-Pertz design, but as the magnitude of the error involved is a function of the specimen damping capacity it will become progressively less as the intrinsic damping of the specimen increases. It does not necessarily follow, therefore, that materials of high damping capacity will show a substantial decrease, as compared with published values, if tested in a modified form of machine as described herein.

#### ACKNOWLEDGEMENTS.

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The construction of the machines and the preparation of the test specimens were carried out by Messrs. Biddulph and Company, Engineers, Manchester; their ability to solve difficult machining problems has contributed very materially to the success of the experiments.

One of the authors (G. A. C.) wishes to record his thanks to his employers, the British Engine, Boiler, and Electrical Insurance Co., Ltd., Manchester, for sanctioning the time he has spent in connection with this work.

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## APPENDIX I.

## PRESSURE TESTS.

## Theory.

The air-friction energy loss over the surface of the inertia member or wheel of the large machine was estimated from the results of the pressure tests, for which purpose the following assumptions were made :

- (i) The total damping of the system is so small that the angular velocity of the wheel varies sinusoidally with time.
- (ii) Whatever the law of variation of the air-damping force with time, it can be represented by a Fourier Series; the only term in this series which will contribute to the energy loss will be the one with a frequency of variation equal to that of the velocity, i.e. the fundamental.
- (iii) It is thus assumed that the effective force producing the energy dissipation can be considered to be sinusoidal and in phase with the velocity. Any variation of the air-friction damping with the amplitude of vibration arises from changes in the maximum value of this effective force, which may result from either changes in the force wave form or phase or a combination of both.
- (iv) The total air-damping force over an area oscillating with uniform amplitude is proportional to the surface area.
- (v) The form of the wheel allows it to be treated as a uniform surface, edge effects being absent.
- (vi) The surface finish of the wheel is uniform and identical with that of the wheel on the large machine.

The pressure tests indicated that the air-friction damping,  $P_a$ , over an oscillating wheel at any frequency increases linearly with  $\theta$ , the maximum angular amplitude of vibration. That is,

$$P_a = A + B\theta,$$

where  $P_a$  is the energy loss per cycle expressed as a percentage of the maximum specimen strain energy during that cycle, and  $A$  and  $B$  are constants for any wheel oscillating at a particular frequency (Fig. 19).

Since the specimen strain energy varies as  $\theta^2$ , then, in order to give a specific damping capacity of the form observed, the total air-friction energy loss must be of the form  $\alpha\theta^2 + \beta\theta^3$ , where  $\alpha$  and  $\beta$  are constants

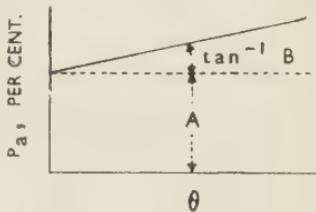


FIG. 19.

at a particular frequency and  $\theta$  is the maximum angular wheel amplitude during the cycle.

The total energy loss over the wheel surface can be divided into two parts, one contributed by the curved surface and the other by the two circular plain surfaces. Both of these must be of the form  $\alpha\theta^2 + \beta\theta^3$ .

It was assumed that the effective force per unit area over an elementary area oscillating with maximum amplitude

$$r\theta_m \text{ is } f(r\theta_m) \cos wt$$

where  $f(r\theta_m)$  is some function of the amplitude of vibration to be determined.

By (iii), the angular amplitude of vibration is  $\theta_m \sin wt$ ; thus the energy loss per cycle over an annular area of width  $dr$  (Fig. 20) is equal to

$$\int_0^{2\pi} 2\pi r^2 \theta_m \cdot f(r\theta_m) \cos^2 wt \cdot d(wt) \cdot dr = 2\pi^2 r^2 \theta_m \cdot f(r\theta_m) \cdot dr.$$

This energy loss must be of the form  $\alpha\theta_m^2 + \beta\theta_m^3$ ; hence  $f(r\theta_m)$  must have been of the form  $kr\theta_m + lr^2\theta_m^2$ , where  $k$  and  $l$  are the amplitude coefficients.

The substitution of this expression for  $f(r\theta_m)$  enables the energy loss over the wheel of the small machine to be calculated by integration. Equating this to the measured value gives the magnitude of the amplitude coefficients at that particular frequency.

These may be used to calculate the air-friction energy loss over the wheel of the large machine, integrals of similar form being involved. The results shown in Fig. 17 were calculated on this basis.

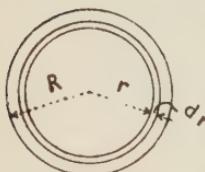


FIG. 20.

## APPENDIX II.

### ESTIMATION OF OBSERVATIONAL ERRORS.

In the case of the small machine, observational errors may arise from three causes :

- (i) Uncertainty in the determination of the instantaneous amplitude, due to imperfect definition of the image and errors in the graduation of the scale.
- (ii) Incorrect zero setting of the image on the scale.
- (iii) Personal error in starting and stopping the watches.

Both (i) and (ii) will become more serious towards the low-amplitude end of the strain-damping characteristic.

The maximum total error due to (i) was assessed at  $\pm 0.015$  cm.;

it was calculated that the percentage error arising in the measurement of the specific damping capacity would be sensibly constant at about  $\pm 4.2\%$  over the major part of the characteristic, but would increase to about  $\pm 6\%$  at the lowest amplitudes.

Serious error arising from (ii) was avoided by neglecting any readings obtained when the image failed to return to zero at the end of a test. This error is generally of constant sign during any one determination, and it was calculated that for a zero error of 0.020 cm. the resultant error in the measurement of the specific damping increased from 0.25% to almost 4% at the lowest amplitudes. The zero error never attained this magnitude in any test.

It was found that, with practice, the error due to (iii) was of the order of 0.1 sec. and certainly less than 0.2 sec. The result of this on the error of measurement is insignificant, since the minimum duration timed was about 5 min.

Thus, the maximum observational error to be expected amounts to  $\pm 4\%$  over the major part of the amplitude characteristic; at the lowest amplitudes it may reach  $\pm 8\%$  in exceptional cases.

It is clear, then, that the accuracy of the observations is determined ultimately by the definition of the image. The optical system of the small machine produced an image 0.025 cm. wide at a scale distance of 120 cm., and the definition was such that the uncertainty in the estimation of the instantaneous amplitude was of the order of 0.010 cm. or less.

### APPENDIX III.

#### THE ESTIMATION OF SPECIFIC DAMPING CAPACITY FROM MEASUREMENTS OF EXPERIMENTAL DECAY CURVES.

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(Communication from the British Non-Ferrous Metals Research Association.)

##### I.—*Introduction.*

THE specific damping capacity is frequently defined as the ratio of the energy dissipated inelastically during a single cycle of vibration to the vibrational energy present at the start of the cycle. The vibrational energy is proportional to the square of the amplitude of vibration, so that, in considering the decay of free vibrations, the energy dissipated per cycle is proportional to the difference of the squares of successive amplitudes.

Thus, for the  $n^{\text{th}}$  cycle of vibration, the specific damping capacity,  $\psi_n$ , has the value :

$$\psi_n = \frac{A_n^2 - A_{n+1}^2}{A_n^2},$$

where  $A_n$ ,  $A_{n+1}$  are respectively the amplitudes at the start of the  $n^{\text{th}}$  and  $(n+1)^{\text{th}}$  cycles.

In general the specific damping capacity is a function of the amplitude, and it is desirable to know its amplitude dependence. However, it is often impracticable to measure successive amplitudes with errors small enough to be acceptable in the calculation of the specific damping capacity, because of the small difference between them. It is usual to make amplitude measurements at the beginning and end of a number of cycles over which the difference in amplitude is large compared with the errors of measurement.

One method of calculating an average damping capacity over this range is to use the expression :

$$\psi = \frac{4}{r} \frac{A_1 - A_{r+1}}{A_1 + A_{r+1}},$$

in which  $A_1$ ,  $A_{r+1}$  are the amplitudes at the beginning and end of the chosen range of  $r$  cycles. The accuracy of this average may be estimated from the errors likely to be incurred in measuring  $A_1$  and  $A_{r+1}$ . However, the relationship between this average,  $\psi$ , and the specific damping capacity at any part of the range is not clear unless the damping-capacity-amplitude relationship is previously known. Even if it is known, for example, that the specific damping capacity is constant, the relationship between the average and specific values is not expressible in a simple way, and a difference, increasing as the arbitrary range,  $r$ , increases, exists between the average and true values. The use of this method of expressing damping capacity involves, in effect, a re-definition of the property.

An alternative method expresses the average damping capacity in terms of the logarithmic decrement, using the expression :

$$\psi = \frac{2}{r} \log_e \frac{A_1}{A_{r+1}}$$

This expression leads to a true average value, with errors of approximation and measurement which are calculable. However, unless it is known *a priori* that the damping capacity is independent of amplitude, in which case the average and specific values are identical, it is impossible to derive a specific value for any particular cycle of vibration within the range considered.

In this note, a method of treating measurements of experimental records is proposed which, in principle, leads to the determination of the specific damping capacity corresponding to any measured amplitude and permits an assessment of the reliability of this determination.

## 2. The Use of Logarithmic Decrement.

In dealing with more than one cycle of vibration the logarithmic decrement,  $\delta$ , defined as the logarithm of the ratio of successive amplitudes, may be usefully employed.

By definition, for the  $n^{\text{th}}$  cycle,  $\delta_n = \log_e \frac{A_n}{A_{n+1}}$ .

The exact relationship between  $\psi_n$  and  $\delta_n$  is,  $\psi_n = 1 - e^{-2\delta_n}$ ,

$$\text{i.e. } \psi_n = \frac{2\delta_n}{1!} - \frac{(2\delta_n)^2}{2!} + \frac{(2\delta_n)^3}{3!} - \dots$$

Thus, when  $\psi_n$  is, say, 0.01 or less, the error involved in writing  $\psi_n = 2\delta_n$  is less than 0.5% of the value of  $\psi_n$ .

The mean value of  $\delta$  over  $n$  cycles is

$${}_{1\bar{\delta}} = \frac{1}{n} \{ \delta_1 + \delta_2 + \dots + \delta_n \},$$

$$\text{i.e. } {}_{1\bar{\delta}} = \frac{1}{n} \left\{ \log_e \frac{A_1}{A_2} + \log_e \frac{A_2}{A_3} + \dots + \log_e \frac{A_n}{A_{n+1}} \right\},$$

$$\text{or } {}_{1\bar{\delta}} = \frac{1}{n} \log_e \frac{A_1}{A_{n+1}}.$$

## 3. Average Damping Capacity.

The mean value of  $\psi$  over  $n$  cycles is :

$$\begin{aligned} {}_{1\bar{\psi}} &= \frac{1}{n} \{ \psi_1 + \psi_2 + \dots + \psi_n \} \\ &= \frac{1}{n} \{ (1 - e^{-2\delta_1}) + (1 - e^{-2\delta_2}) + \dots + (1 - e^{-2\delta_n}) \}. \end{aligned}$$

When  $\psi_r < 0.01$ , ( $1 < r < n$ ),

$$\begin{aligned} {}_{1\bar{\psi}} &= \frac{2}{n} \{ \delta_1 + \delta_2 + \dots + \delta_n \} \\ &= 2 {}_{1\bar{\delta}} = \frac{2}{n} \log_e \frac{A_1}{A_{n+1}}, \end{aligned}$$

with an approximation error less than 0.5%.

4. Errors in the Estimation of  ${}_{1}\bar{\delta}_n$ .

Consider the uncertainty in estimating the mean logarithmic decrement,  ${}_{1}\bar{\delta}_n$ , due to error in the experimental measurements required for the calculation :

$${}_{1}\bar{\delta}_n = \frac{1}{n} \log_e \frac{A_1}{A_{n+1}}.$$

It is assumed for purposes of calculation that  $n$  is exact, as it might in fact be made by suitable refinement of technique. The value of  $A_1$  and of  $A_{n+1}$  are each subject to an uncertainty in measurement of  $\pm \varepsilon$  so that the estimate of  ${}_{1}\bar{\delta}_n$  is :

$$\begin{aligned} {}_{1}\bar{\delta}_n &= \frac{1}{n} \log_e \frac{A_1 \pm \varepsilon}{A_{n+1} \mp \varepsilon} \\ &= \frac{1}{n} \log_e \frac{A_1}{A_{n+1}} \left(1 \pm \frac{\varepsilon}{A_1}\right) \left(1 \mp \frac{\varepsilon}{A_{n+1}}\right)^{-1} \\ &= \frac{1}{n} \log_e \frac{A_1}{A_{n+1}} + \frac{1}{n} \log_e \left(1 \pm \frac{\varepsilon}{A_1}\right) \left(1 \mp \frac{\varepsilon}{A_{n+1}}\right)^{-1} \end{aligned}$$

If  $\varepsilon/A_{n+1}$  does not exceed, say, 0.1 (so that  $\varepsilon/A_1 < 0.1$ ), this may be written :

$${}_{1}\bar{\delta}_n = {}_{1}\bar{\delta}_n + \frac{1}{n} \log_e \left\{ 1 \pm \varepsilon \left( \frac{1}{A_1} + \frac{1}{A_{n+1}} \right) \right\},$$

which further simplifies with small error to :

$${}_{1}\bar{\delta}_n = {}_{1}\bar{\delta}_n \pm \frac{\varepsilon}{n} \left( \frac{1}{A_1} + \frac{1}{A_{n+1}} \right).$$

## 5. Application to the Estimation of Average and Specific Damping Capacity.

The average logarithmic decrement over  $n$  cycles, without limitation as to the values of  $\delta_1 \dots \delta_n$ , is :

$${}_{1}\bar{\delta}_n = \frac{1}{n} \log_e \frac{A_1}{A_{n+1}}.$$

This may be measured with an uncertainty of less than  $\pm \frac{\varepsilon}{n} \left( \frac{1}{A_1} + \frac{1}{A_{n+1}} \right)$  provided that  $\varepsilon/A_{n+1}$  is less than, say 0.1.

The exact expression for average damping capacity over  $n$  cycles,  ${}_{1}\psi_n$ , in terms of logarithmic decrement, is simple only if :

(a)  $\psi_1 = \psi_2 = \dots \psi_n = {}_{1}\psi_n \equiv \psi$ , in which case  $\delta_1 = \delta_2 = \dots \delta_n = {}_{1}\bar{\delta}_n \equiv \delta$  and

$$\psi = 1 - e^{-2\delta} = 1 - e^{-\left\{ \frac{2}{n} \log_e \frac{A_1}{A_{n+1}} \pm \frac{2\varepsilon}{n} \left( \frac{1}{A_1} + \frac{1}{A_{n+1}} \right) \right\}}.$$

(b)  $\psi_1 \dots \psi_n$  are small enough, say less than 0.01, in which case :

$$_1\bar{\psi}_n = 2_1\bar{\delta}_n = \frac{2}{n} \log_e \frac{A_1}{A_{n+1}} \pm \frac{2\varepsilon}{n} \left( \frac{1}{A_1} + \frac{1}{A_{n+1}} \right).$$

Consider the curve obtained by plotting values of  $_1\bar{\delta}_n$  for a series of values of  $n$  against the corresponding value of  $n$ . If there were no uncertainty in the values of  $\frac{1}{n} \log_e \frac{A_1}{A_{n+1}}$  and if  $\delta_1 = \delta_2 = \dots \delta_n = \delta$ , the plotted points would lie exactly on a straight line drawn parallel to the  $n$ -axis and cutting the  $_1\bar{\delta}_n$ -axis at  $_1\bar{\delta}_n = \delta$ .

Thus, if in such a plot of experimental data this straight line can be drawn through a number of points in the range  $n = 1$  to  $n = r$ , having regard to the calculated uncertainty in the estimation of each value,  $_1\bar{\delta}_n$ , it may be said that the logarithmic decrement is constant over this range, as far as can be estimated by the method. The specific damping capacity over the range may be calculated from the value of  $\delta$  thus obtained using the exact expression or the approximation  $\psi = 2\delta$  where appropriate. The estimate of uncertainty in the value of  $\delta$  will depend on the comparative length of the range of  $n$  over which the calculated uncertainty in  $_1\bar{\delta}_n$  is relatively low and constant.

In general, however, the plot of  $_1\bar{\delta}_n$  for various values of  $n$  over the whole of the measurable range must be expected to contain departures from a straight line parallel to the  $n$ -axis which will be revealed more significantly as the value of  $n$  increases, and it may be possible to fit the points to a curve from which  $\delta_n$  is expressible approximately as a function of  $n$ , i.e. from which  $\psi_n$  may be estimated as a function of  $A_n$ .

Thus :

$$_1\bar{\delta}_n = \frac{1}{n} \{ \delta_1 + \delta_2 + \dots \delta_n \}.$$

This may be written :

$$_1\bar{\delta}_n = \frac{1}{n} \{ \delta_1 + (\eta_1 + \delta_1) + (\eta_2 + \delta_1) + \dots (\eta_{n-1} + \delta_1) \},$$

$$\text{i.e. } _1\bar{\delta}_n = \delta_1 + \frac{1}{n} \{ \eta_1 + \eta_2 + \dots \eta_{n-1} \}.$$

At any value of  $n$ , the departure of the curve for  $_1\bar{\delta}_n$  against  $n$  from a straight line through  $\delta_1$ , parallel to the  $n$ -axis is :

$$_1\bar{\eta}_n = \frac{1}{n} \{ \eta_1 + \eta_2 + \dots \eta_{n-1} \}.$$

If  $n_1\bar{\eta}_n$  is plotted against  $n$ , it may be possible to fit a curve to the points whereby  $_1\bar{\eta}_n$  is expressible as a function of  $n$  and thence to express  $\delta_n$  as a function of  $n$ .

Example.

Consider the function  $\frac{\varepsilon_n}{1\bar{\delta}_n} = \pm \frac{\varepsilon}{n} \left( \frac{1}{A_1} + \frac{1}{A_{n+1}} \right) / 1\bar{\delta}_n$ .

It is convenient to examine this function in a case where it is known *a priori* that  $\delta_n$  is constant. In this case

$$A_{n+1} = A_1 e^{-n\delta},$$

i.e.

$$\frac{\varepsilon_n}{\delta} = \pm \frac{\varepsilon}{A_1} \left( \frac{1 + e^{n\delta}}{n\delta} \right).$$

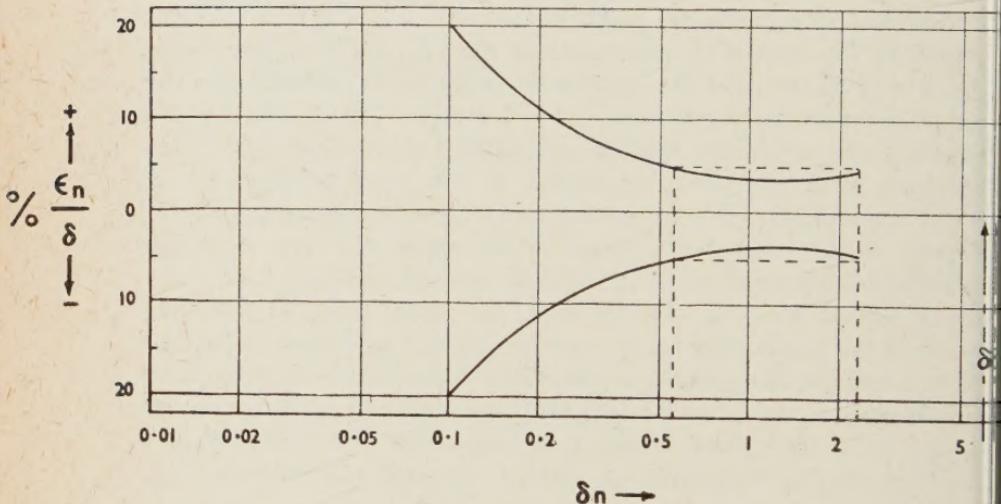


FIG. 22.

The error approximation is regarded as valid for  $\frac{\varepsilon}{A_{n+1}} < 0.1$ , i.e. over the range  $n = 1$  to  $n = n_{\max}$ , where  $\frac{\varepsilon e^{n_{\max}}}{A_1} = 0.1$ .

Fig. 22 shows the uncertainty envelope expressed as a percentage of the value of  $\delta$  over the range  $n = 1$  to  $n = n_{\max}$  in the case where  $\frac{\varepsilon}{A_1} = 10^{-2}$ . Fig. 23 is a similar curve for  $\frac{\varepsilon}{A_1} = 10^{-3}$ .

Fig. 24 shows the variation of amplitude ratio with  $\delta_n$ .

Referring to Figs. 22 and 24, it is seen that there is a range  $\delta_n = 0.56$  to  $\delta_n = 2.3$ , with corresponding amplitude range  $\frac{A_{n+1}}{A_1} = 0.6$  to  $\frac{A_{n+1}}{A_1} = 0.1$ , in which the uncertainty in estimating  $1\bar{\delta}_n$  is

within  $\pm 5\%$ . Similarly, for Fig. 23, in the range  $\delta n = 0.1$ ,  $\frac{A_{n+1}}{A_1} = 0.9$  to  $\delta n = 4.6$ ,  $\frac{A_{n+1}}{A_1} = 0.01$ , there is an uncertainty of less than  $\pm 2\%$  in estimating  ${}_{10}\bar{\delta}_n$ .

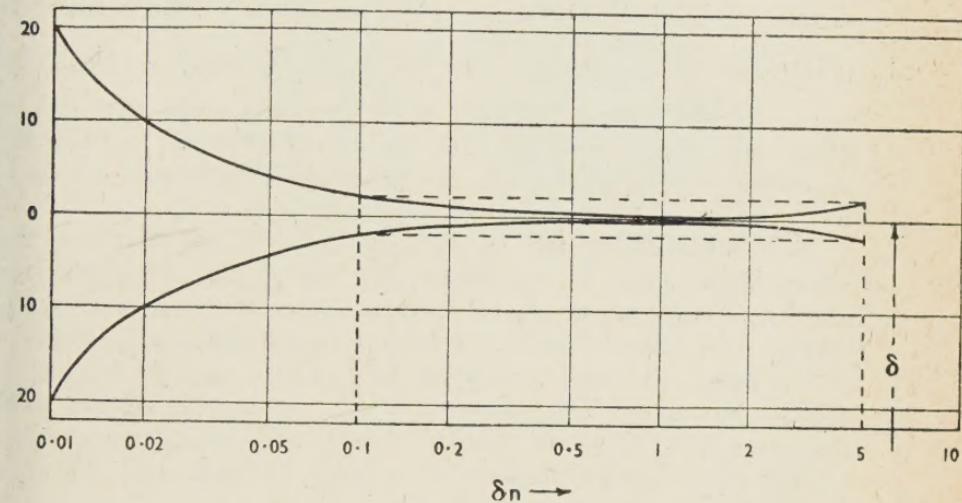


FIG. 23.

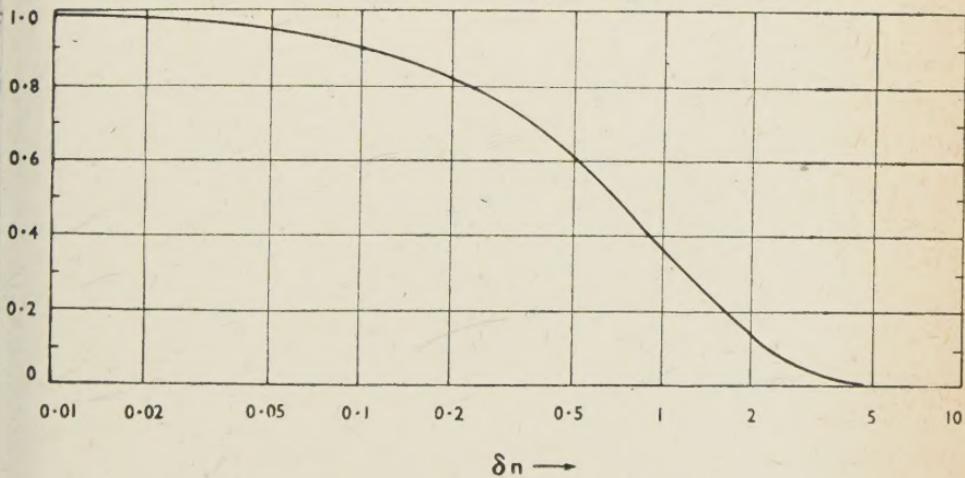


FIG. 24.

When, for example,  $\delta = 10^{-4}$ , the corresponding ranges of  $n$  are  $n = 5600$  to  $23,000$  and  $n = 1000$  to  $46,000$ , respectively. If  $\delta = 10^{-1}$ , the ranges are  $n = 6$  to  $23$  or  $n = 1$  to  $46$ .

## 6. Method of Estimating Specific Damping Capacities.

The nature of the error envelopes discussed in the previous section indicates the possible usefulness of the method proposed for the estimation of specific damping capacities in the general case when the decrement varies as a function of the amplitude. This proposal is simply that  ${}_1\bar{\delta}_n = \frac{1}{n} \log_e \frac{A_1}{A_{n+1}}$  should be plotted against  $n$  on a linear scale. In view of the significance of each result, a mean curve can be drawn, with gain in accuracy, over that part of the range in which the uncertainty of estimating  ${}_1\bar{\delta}_n$  is comparatively low and constant. Extrapolation of the curve back to  $n = 1$  will give  $\delta_1$ .

This extrapolation will be the more reliable the shorter is the extrapolation range in comparison with the plotted range and the smaller the departure of  ${}_1\bar{\delta}_n$  values from a straight line parallel to the  $n$ -axis. The accuracy of the estimate may be approximately assessed in a given case. If desired, an attempt may then be made to estimate  $\delta$  as a function of  $n$ . The estimation of  $\psi_1 \dots \psi_n$  may be effected from the values of  $\delta$  so obtained. Clearly, in cases where it is assumed or can be shown on the above-mentioned lines that  $\delta_1 \simeq \delta_2 \simeq \dots \delta_n = \delta$  and is, say, less than 0.01, it may be said that :

$${}_1\bar{\delta}_n \equiv \delta = \frac{1}{n} \log_e \frac{A_1}{A_{n+1}}, \quad \text{i.e. } {}_1\bar{\psi}_n \equiv \psi = \frac{2}{n} \log_e \frac{A_1}{A_{n+1}}.$$